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PRELIMINARY TESTS OF NOSE- AND SIDE-ENTRANCE BLOWER COOLING SYSTEMS FOR RADIAL ENGINES

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SUMMARY

Two cowling systems intended to reduce the drag and improve the low-speed cooling characteristics of conventional radial engine cowlings were tested in model form to determine the practicability of the methods. One cowling included a blower mounted on the rear face of a large propeller spinner which drew cooling air in through side-entrance ducts located behind the equivalent engine orifice plate. The air was passed through the equivalent engine orifice plate from rear to front and out through a slot between the spinner and the engine plate. The blower produced substantially all the power necessary to circulate the cooling air in some cases, so the quantity of air flowing was independent of the air speed. Two types of blowers were used, a centrifugal type and one using airfoil blades which forced the air outward from the center of rotation.

The other cowling was similar to the conventional N.A.C.A. cowling except for the addition of a large propeller spinner nose. The spinner was provided with a hole in the nose to admit cooling air and blower blades to increase the pressure for cooling at low speeds.

The tests show that with both cowling types the basic drag of the nacelle was reduced substantially below that for the N.A.C.A. cowling by virtue of the better nose shape made possible by the spinner. The drag due to the side-entrance ducts was nearly zero when the openings were closed or when the blower was drawing in a certain quantity of air in proportion to the air speed. The drag increased, however, when air was allowed to spill from the openings.

The nose-entrance blower showed considerable promise as a cooling means although the blower tested was relatively inefficient, owing to the fact that the blower compartments evidently were expanded too rapidly under the conditions imposed by the design.

Further model tests are proposed to improve the side-entrance cowling properties. A nose-entrance blower of improved design is being built for tests with an engine.

INTRODUCTION

This is the third report describing preliminary tests of radial engine cowlings intended to improve the N.A.C.A. cowling from the standpoints of drag and cooling at low air speeds. The first report, reference 1, described a wing-duct system wherein the cooling air enters ducts in the wing roots, passes through the baffle passages from rear to front, amd exhausts through an annular slot near the front of the cowling. The results from the tests indicated the system to be practicable only for airplanes with relatively thick wings, owing to the necessity of providing space for the entrance ducts.

The second report, reference 2, describes some tests with blowers operating in conjunction with the wing-duct system described in reference 1. The object of these tests was to determine the characteristics of several blowers suitable for cooling radial engines. The tests indicated that blowers mounted on propeller spinners are capable of cooling present-day engines under all flight conditions, regardless of whether the cooling air was drawn in from the wing ducts or elsewhere. The over-all efficiency exceeded 70 percent under certain conditions which showed that blower cooling was within the range of being practicable.

The present report describes additional tests of blowers intended to cool radial engines. A part of the tests covered in this paper are similar to those of reference 2 except for the location of the entrance ducts. Instead of drawing the cooling air in through entrances located in the leading edge of a wing, the air is drawn in through openings located in the side of the engine cowling immediately in front of the wing. The purpose of locating the entrances in the side of the nacelle is to provide a system suitable for a large variety of airplane designs irrespective of the thickness of the wing, and also to provide a system which requires no control from the pilot. The entrances are intended to be located at such an angle that the pressure across the engine baffles remains substantially constant for a given engine speed independent of the air speed.

The present report also describes tests of a blower system which draws the air in through a hole in the propeller spinner, passes the cooling air through the engine

baffles from front to rear, and exhausts it out an annular slot at the rear of the engine. This cooling system is similar to the present conventional type except for the addition of a large blower spinner. The object of this system is to provide a low drag cowling capable of cooling the engine at low speeds without the necessity of altering the conventional cowling materially.

APPARATUS AND METHODS

A description of the basic wing-nacelle combination used for the tests is given in references 1 and 2. Drawings for blowers 2 and 4 are repeated in figures 1 and 2.

Blowers tested with side entrances.- Plans for making the side-entrance tests were adopted after several blowers were tested in conjunction with the wing-duct system described in reference 2, so it became necessary to alter the cowling to accommodate the side entrances. Several steel members supporting the motor and the cowling interfered with locating the entrances immediately in front of the wing leading edge. The entrance ducts were, consequently, located in front of the supporting members in order to try out the system without delay. Several tests were made with the ducts in the forward position as shown in figure 3. Tests were made with the plane of the entrance ducts located at several angles with the thrust axis; 0°, 15°, and 25°.

The first results from the tests showed that the system satisfied the requirement of engine cooling which would be independent of the air speed, so further tests were made with the entrances moved back to the leading edge of the wing. (See figs. 4, 5, and 6.) Also the effect of building up the sides and rear of the openings was determined for both positions. Blower 2, with guide vanes in the exit slot, and blower 4 were used in all the side-entrance tests.

The total head loss across the engine orifice plate and the quantity of air flowing was measured to determine engine cooling characteristics.

Blower 5.- Blower 5 is essentially a centrifugal blower built into a propeller spinner. (See figs. 7 and 8.) Air is drawn in through a hole in the nose of the

spinner and forced through the engine baffles from front to rear. The spinner blower consists of an outer skin that fairs smoothly into the body, two inner surfaces which form the cooling air passage through the spinner, and several radial partitions or blades that act to impart translational velocity to the air passing through. Pressure is produced by centrifugal force acting on the air tending to throw it away from the center of rotation. The passage is so shaped that any radial displacement of the air also results in an axial component. It is intended that the rotational component of the air be taken out by the cylinders of the engine, thereby making use of all the energy in the stream for cooling purposes without complicating the installation with guide vanes.

Preliminary tests with blower 5 showed that the engine could not be simulated entirely by a calibrated orifice plate owing to the lack of uniform pressure distribution over the plate. A plate was used, however, for the purpose of restricting the flow, and guide vanes were incorporated to remove the twist in the stream. An attempt was first made to measure the quantity of air flowing by means of a number of static and total-head tubes in the exit slot. The pressure drop across the engine was measured by means of additional tubes located in front of the orifice plate. It was found that the measurements made by this method were not reliable owing to the nature of the flow exhausting from the blower, so the set-up was altered to facilitate more accurate measurements. The exit slot was closed and a tail pipe was installed beneath the wing at the rear of the nacelle to replace the exit slot. The tail pipe made possible an accurate measurement of the quantity of air flowing and the total head of the exhaust air. The total head in front of the engine orifice plate was measured by means of a bank of tubes. Static tubes were also included to determine the velocity distribution.

The problem of determining the effective pressure drop across the engine orifice plate was not a simple one for blower 5 because of the uneven pressure distribution. A method was developed which involves an integration of the power in the stream ahead of the orifice plate. The total power in the stream is then divided by the flow quantity determined from the tail-pipe measurements to arrive at an effective pressure ahead of the orifice plate. The pressure drop and efficiency are then determined in the usual manner.

SYMBOLS AND EQUATIONS

$$K_1 = \frac{\Delta P_e}{\rho n^2 d^2}$$

$$K_2 = \frac{\text{Power required by blower}}{\rho n^3 d^5}$$

$$K_3 = \frac{Q}{n d^3}$$

$$K_4 = \frac{\text{Thrust of blower}}{\rho n^2 d^4}$$

$$\eta_t = \frac{K_1 K_3}{K_2 - \frac{V}{nd}\frac{K_4}{\eta}},$$ efficiency of blower system

$$K_{1_{\text{entrance}}} = \frac{\Delta P_{\text{entrance}}}{\rho n^2 d^2}$$

$$K_e = \frac{A_e}{A_c} = \frac{K_3 d^2}{A_c \sqrt{2K_1}},$$ (conductivity in terms of blower coefficients)

$$\frac{A_e}{d^2} = \frac{K_3}{\sqrt{2K_1}},$$ (restriction constant)

$$C_{D_P} = \frac{\text{Drag added by nacelle}}{qA_c}$$

$$C_{D_{(W+N)}} = \frac{\text{Drag of wing and nacelle}}{qA_W}$$

$$C_{L_{(W+N)}} = \frac{\text{Lift of wing and nacelle}}{qA_W}$$

Q, quantity of cooling air, cubic feet per second.

ρ, mass density of air, slugs per cubic foot.

n, rotational speed of blower, revolutions per second.

d, design diameter of blower, feet.

V, air speed, feet per second.

Δp_e, pressure drop across engine, pounds per square foot.

$\Delta p_{entrance}$, static pressure drop across entrance, pounds per square foot.

η, propeller efficiency.

K_e, engine conductivity.

A_e, orifice area of engine.

A_c, projected area of engine (or cowling).

A_W, wing area.

RESULTS

The test results are presented in the form of coefficients outlined in the list of symbols and equations. These coefficients are essentially the same as given in reference 2, except for the pressure coefficient, K_1, and the efficiency, η_t. The pressure coefficient obtained in the wing-duct system, K_{1_t}, was based on the pressure drop across both the entrance ducts and the engine orifice plate. This procedure was followed in order to combine two independent variables. It was not practicable to continue this method for the side-entrance tests because of the difficulty in determining the total-head drop across the entrance ducts. The pressure coefficient, K_1, is based upon the pressure drop across the engine orifice plate alone for the side-entrance tests.

The efficiency is the true efficiency of the blower system, being the ratio of useful power expended in forcing air through the engine orifice plate to the brake power supplied. The propeller efficiency is neglected, however, in translating the drag into power; so the computed efficiency is too low for conditions when the blower is producing thrust and too high for drag conditions.

The static pressure differences across the side-entrance ducts were measured as a means of determining how much the ducts were scooping up the air, and how much the

blowers were sucking the air into the cowling from the outside. The results are presented in the form of a pressure coefficient, $K_{1_{entrance}}$.

The results of the tests presented in this paper are outlined as follows:

I. Blowers with side entrances:

A. Entrances in forward position:

(1) Entrance openings in original condition:

a. Blower 2, figures 10 to 15.

b. Blower 4, figures 16 to 21.

(2) Entrance lips built up:

a. Blower 2, figures 22 to 24.

b. Blower 4, figures 25 to 27.

(3) Comparison between original and condition with lips built up:

a. Blower 2, figure 28.

b. Blower 4, figure 29.

B. Entrances in rear position, lips built up:

(1) Blower 2, figures 30 to 34.

(2) Blower 4, figures 35 to 39.

C. Various comparisons, figures 40 to 45.

II. Blower with nose entrance, figures 46 to 53 (blower 5).

Side-Entrance Tests

One of the objects of the investigation with side entrances was to determine the possibilities of developing an engine cooling system which would require no control from the pilot for the maintenance of the proper amount of

cooling air. It would appear that, if a blower were used as the means for creating the pressure drop across the baffles and the air were taken into the system at nearly right angles to the wind direction, the pressure would be substantially independent of the speed of the airplane. Under these conditions the cooling air pressure would be proportional to n^2 of the engine and the volume proportional to n. Since the power output with a propeller load is proportional to n^3, the ratio of cooling air quantity to power output would increase as the engine is throttled. This means that, if a cooling system were designed for continual operation at the cruising or high-speed ratings of the engine, the cooling would probably be more than adequate for reduced rotational speeds. Variations in the amount of air for different flight attitudes or speeds from that specified by the n relation could possibly be obtained with the inlet entrances set at some angle or location other than the one providing pressure independent of the speed. For example, if an entrance duct were located on the belly of a nacelle, the pressure obtained in the climb would be greater than that for level flight for the same rotational and forward speeds, owing to the increased angle of attack. Some effects of entrance angle, shape, position, and drag have been studied and are discussed as follows:

Effect of inlet entrance angle.- The general effect of increasing the angle between the plane of the entrance opening and the thrust axis is to increase the effect of the forward speed upon the amount of cooling air entering. In other words, as the rear of the entrance openings are moved away from the surface of the cowling, the entrances tend to scoop up more air. This effect is illustrated in figures 10 to 15 for blower 2, and 16 to 21 for blower 4.

Referring to figure 10, it may be noted that there is scarcely any change in K_1 with V/nd for the condition of the entrance set at 0° and orifice 30. The pressure across the engine increases slightly with V/nd for an entrance setting of 15° and more so for 25°.

The amount of air flowing influences the relationship between the pressure and the entrance angle, as may be seen by comparing the results for the different orifices. While a zero angle provides uniform pressure for the lowest flow condition, a 15° angle is necessary for the highest flow condition investigated (orifice 0).

The general effect of increasing the entrance angle was to increase the efficiency (see figs. 14 and 20), due chiefly to the increase in the pressure without a proportionate increase in the power. The effect of the entrance angle on the drag or thrust was small in general. (See figs. 13 and 19.) The underlying reasons for the efficiency increase with increased entrance angle are that the blowers are aided by the free stream velocity, and also the entrance losses are reduced.

A measure of the pressure contributed by the free stream is shown in figures 15 and 21. $K_{1_{\text{entrance}}}$ is a pressure coefficient based on the static pressure across the entrance ducts. A positive value indicates the static pressure is lower outside of the cowling, or in other words, the blower is drawing the air through the entrance ducts. A negative value indicates the free stream velocity is building up a pressure within the cowling and assisting the blower. Figure 15 shows that blower 2 furnished the pressure drop across the entrance ducts for the zero angle condition but, that for the 15° and 25° positions, the free stream velocity decreased the amount of pumping required and even assisted the blower for the high V/nd conditions.

The results of tests of blower 4 are somewhat different from those for blower 2 (see fig. 21) in that the free stream velocity did not build up the pressure within the cowling to the same extent as for blower 2. The only explanation for this difference lies in the differences in the shapes of the cowlings in front of the entrances and the differences in the velocity of the flow leaving the blower. Blower 2 cowling was equipped with guide vanes in the exit slot which modified the shape; also the exhaust velocity was higher than for blower 4, which may have accounted for some boundary-layer-control effect over the cowling near the entrance ducts.

Effect of building up the entrance lips.- The results from the first tests of blowers 2 and 4, given in figures 10 to 21, showed that the peaks of the efficiency curves were reached at fairly low values of V/nd. The decrease in efficiency at higher values of V/nd was apparently due to increases in the drag of the side entrances. This effect was more pronounced for blower 4 than for blower 2 because of the differences in the amount of air spilling from the entrance openings. It may be noted that the effi-

ciency curves reached their peaks at approximately zero values of K_4 which indicates that for higher values of V/nd the drag power, due to the entrances, increased faster than the useful power. That blower 4 was more critical than blower 2 may have been due to the smaller volume handled by blower 4; hence, there was more spillage at the higher values of V/nd.

An attempt to improve the entrance shape was made by building up the lips of the openings, as shown in figure 3. It was thought that by so doing some of the turbulence introduced by the guide vanes would be smoothed out by the lips. The test results for the condition of the entrances set 25° are given in figures 22 to 27. Typical comparisons showing the effects of the lips are shown in figures 28 and 29. The efficiencies were increased for both blowers, due partly to reductions in drag and partly to increases in the pressure across the engine orifice plate. The building up of the entrance lips had somewhat the same effect as increasing the entrance angle.

Effect of moving the entrances.- The tests with the side entrances in the front position showed sufficient promise in this system to warrant rebuilding the cowling structure so that the entrances could be located back near the wing leading edge, thereby simulating the conditions imposed by the presence of an engine. (See fig. 4.) The results of the tests with the entrances moved back and set 15° are given in figures 30 to 39. In figures 40 and 41 are typical results for the conditions of the entrances in both the front and rear positions. The entrance lips were built up for the rear position tests but not for the front position. The effect of the lips has been discussed, however, for the front position tests. The blower 2 results show that moving the entrances back and adding the entrance lips had about the same effect as would be expected from the lips alone, namely, an increase in pressure and a reduction in drag at high V/nd values. The blower 4 results, however, show a much more pronounced effect in that the pressure was nearly doubled at a V/nd value of 5. The blower 4 results indicate that the entrance angle should be less than 15° for a zero change in pressure for changes in V/nd. The probable cause for the building up of the pressure is that the entrances are located in a positive pressure region in front of the wing.

Effect of the blade-angle setting of blower 4.- One of the important design parameters of blower 4 hitherto

neglected is the blade-angle setting. The principle of operation of this blower is the same as for a propeller, so it is obvious that the blade angle should be considered. Changing the blade angle was not an easy task for the model blower, so only one additional blade setting was investigated, that of 37°. (The basic setting was 27°.)

The results given in figures 35 to 39 show that increasing the blade angle 10° increased the pressures from about 15 to 35 percent depending upon the orifice used and the V/nd. The percentage increase in pressure was greatest for the highest flow condition, as would be expected. The tests show no indication of the blades stalling even for smallest flow condition, which suggests that a higher blade setting could be used with profit, particularly for the highest flow condition.

The power coefficients were increased in about the same proportion as the pressure coefficients due to the blade-angle change. The efficiencies were likewise increased substantially over the entire operating range.

<u>Comparison between blowers 2 and 4.</u>- The results given in this paper for blowers 2 and 4 are not comparable because the design diameters are different. If the blowers were compared on a basis of the same value of A_e/d^2 in order to proportion the orifice area to the design blower area, the comparison would still be in error because then the entrance duct areas would not be comparable. The only legitimate method to compare the blowers for these tests is to convert the coefficients to the same basic design diameter and use the same orifice restriction. Such a comparison is given in figure 42 wherein the coefficients are based on the cowling diameter of 20 inches. The characteristics are strikingly different for the two blowers. Blower 2 produced nearly twice the pressure and absorbed over three times the power as blower 4 for the zero V/nd condition. Blower 4 was much more efficient at low V/nd values than blower 2, but the two blowers had the same efficiency at a V/nd value of 2.4. The reason for the relatively lower efficiency at high V/nd values for blower 4 was the relatively higher drag in proportion to the useful work done. It is shown elsewhere in this paper that the drag of the side entrances increases very rapidly if the air is allowed to spill out of the openings. As long as the blower draws the air into the cowling the increment of drag remains low. Blower 4 did not draw as much air in through the entrances as blower 2 for the tests under con-

sideration, and the increment in drag at a V/nd value of 3.0 was twice as much for blower 4 as for blower 2.

Comparison between blowers 2 and 3.- Unfortunately blower 3 was not available for the present tests so no direct comparison can be made. A comparison is made in reference 2, however, between blowers 2 and 3, which shows that blower 3 is definitely superior to blower 2 to the extent of being about 20 percent more efficient (60 percent maximum efficiency as compared to 50 percent). It is not unreasonable to presume, therefore, that blower 3 would also be more efficient than blower 2 when used with the side-entrance ducts.

Drag of cowlings with side entrances.- One of the chief objects of the present research is to reduce the form drag of present-day cowlings for radial engines. The basic method employed for doing this is to encase the engine completely in as nearly a streamlined body as possible. The problem then is to cool the engine without destroying the low drag properties of the streamline body. In the present method for cooling, the form drag, due to the side entrances, was very small in general and could not be measured for several tests. The following table gives the results of several drag tests with the side entrances:

Table of Nacelle Form Drag Values in Presence of Wing

Streamline Body (See fig. 9)

	$C_{D_P} = 0.039$
Blower 2, side entrance set 0°, condition A,	$C_{D_P} = 0.045$
Blower 2, side entrance set 15°, condition A,	$C_{D_P} = 0.045$
Blower 2, side entrance set 25°, condition A,	$C_{D_P} = 0.045$
Blower 4, side entrance set 15°, condition A,	$C_{D_P} = 0.045$
Blower 4, side entrance set 25°, condition A,	$C_{D_P} = 0.045$
Blower 2, side entrance set 25°, condition B,	$C_{D_P} = 0.059$
Blower 2, side entrance set 25°, condition C,	$C_{D_P} = 0.100$
Blower 4, side entrance set 25°, condition B,	$C_{D_P} = 0.053$
Blower 2, side entrance set 15°, condition D,	$C_{D_P} = 0.039$
Blower 4, side entrance set 15°, condition D,	$C_{D_P} = 0.039$

(Note: Blower 2 values do not include the drag due to guide vanes in exit slot.)

Condition "A" - side entrances in forward position and openings covered.

Condition "B" - same as "A" except lips are added to the entrance openings.

Condition "C" - same as "B" except openings are uncovered.

Condition "D" - same as "B" except entrances in rear position.

If the drag of the streamline body shown in figure 9 is taken as the minimum drag likely for this set-up ($C_{D_P} = 0.039$), the drag due to the side entrances and other irregularities of the blowers was in general small. Increasing the angle of the entrances had no measurable effect on the drag. The drag increased slightly when the lips were added to the mouths of the entrances. The drag coefficient was reduced to the value 0.039 by moving the entrances back against the wing. All of the drag tests which were used as bases for computing the efficiency of blowers were made with the entrance openings sealed over with plates. Whatever drag resulted from removing the plates was, therefore, accounted for in the efficiency evaluation. It may be noted (condition C) that the drag of nacelle was nearly doubled by removing the plates. This high drag of the uncovered entrances accounts for the diminishing efficiencies of the blowers as the V/nd increases, or in other words, as the operating conditions approach that of the pure drag condition. There appears to be at least two solutions to the problem:

First, the size of the entrance openings should not be too large. It is obvious that, if only one entrance had been uncovered for the drag run (condition C), the increment drag, due to uncovering, would have been only half as great as noted for two. It is true that the internal losses will be greater with the blower running for such conditions unless extra precautions are taken to expand the air upon entering the cowling; but, if the drag is the chief source of the energy loss, then it should be reduced even at the expense of a small additional internal loss.

Second, the drag, due to side entrances, possibly can be reduced with more careful designing. The cause of the drag due to the uncovered entrances was evidently due to the introduction of turbulence or separation behind the entrance openings due to the fact that the air was scooped

up by the guide vales and then spilled out over the leading edges. Double cambered guide vanes with well-rounded leading edges might result in a reduction of the turbulence created and the drag increment. Guide vanes of this type could also be designed to expand the air upon entering the cowling so that smaller entrances could be used without sacrificing internal energy in the cooling air stream. This suggests further tests.

In figure 43 polar curves are given for the conditions of the wing alone, the streamline body, and blower 2 with uncovered side entrances set 15° in rear position. The chief object of this comparison is to show that the side entrances had no particularly bad effects upon the stalling characteristics of the wing.

<u>Comparison between side-entrance and wing-duct systems</u>.- The essential difference between the wing-duct cowling with blowers described in reference 2 and the side-entrance cowling is the angle of the entrances to the thrust axis. The angle of the plane of the entrance mouth is 90° to the thrust axis for the wing-duct cowling and 0° to 25° for the side-entrance cowling. The method for measuring the pressures was different also; the pressure was measured across both the entrance duct and engine orifice plate for the wing-duct system, and only across the engine orifice plate for the side-entrance system. If it is assumed that the wing-duct entrances are large in proportion to the engine orifice so that the entrance losses can be neglected, then the two systems can be compared directly.

In figure 44 are presented typical results of blower 2 operating in conjunction with the two cowling systems. The comparison shows the marked differences of the effect of increasing V/nd on the pressure coefficients for the two systems. The efficiency of the side-entrance system is much lower at high V/nd values than for the wing-duct system, due to the lower pressures without corresponding decreases in drag. The basic reason for this lower efficiency is not the pressure difference but the higher increment of parasite drag due to the air spilling from the side entrances. The drag for the wing-duct system happens to be about the same as for the side-entrance system but it arises in part from forcing air through the system, as may be computed from the relation, $\Delta D = \Delta pQ/V$.

Figure 45 shows the same effects for blower 4 as for blower 2. The efficiency differences are even more pro-

nounced, however, due to the greater spillage from the side entrances for blower 4 than for blower 2.

Design considerations.- The present test results show that blower cooling systems incorporating side entrances possess certain desirable features, such as low basic drag and cooling nearly independent of the air speed. Other considerations, such as cooling of the engine compartment and flexibility in the basic design of airplanes, add to the attractiveness of the scheme. There is one problem brought out by these tests, however, which should be considered more fully in order that efficient cooling systems based on this method can be designed with more understanding. That problem involves the size and shape of the entrance ducts.

These tests show that air spillage is the chief factor reducing the efficiency at high speeds. The results show further that the blowers eliminate the spillage at low speeds, or low values of V/nd, but as the V/nd increases, the spillage increases, because the amount of air flowing past the entrances increases in proportion to the amount of air entering. The use of small entrances in relation to the amount of air entering obviously reduces spillage, but the losses through the entrance openings increase, owing to the higher velocities unless efficient diffusers are incorporated. Spillage, or the effect of spillage, turbulence, or separation, might also be reduced or eliminated through the use of guide vanes of better shapes than those used in these tests. The angle of attack of the guide vanes, the radius of curvature or camber, the thickness, and the leading-edge radius may all contribute to the character of flow. These subjects were not studied in the present tests program because the tests were only intended to scout the potentialities of the cooling system in a general manner in order that a basis could be established for future research if the results warranted. For this reason recommendations regarding the design of the most efficient types of entrance ducts cannot be included here.

A method outlining the design of blowers is given in reference 2 and will not be repeated.

One of the advantages of the side-entrance system previously mentioned is that the method lends itself to a great variety of engine installations. For example, if a high performance fighter were being contemplated and a

cannon operated by the pilot were essential, a single radial engine could be installed behind the pilot and be effectively cooled at all speeds by means of the side-entrance blower system. If a pusher propeller or oppositely rotating pusher propellers were mounted on a short extension shaft, the weight of the installation would be definitely less than for a liquid-cooled engine installation, and the drag of the airplane probably would not be greatly different. In this example the blower cooling system would permit the use of a radial engine for a purpose which would otherwise dictate the use of a liquid-cooled engine, and without sacrificing performance.

Nose-Entrance Tests

One of the admirable qualities of the N.A.C.A. cowling is its simplicity. The only two prominent disadvantages are the large blunt nose which contributes to the drag of the installation and the poor cooling qualities at low air speeds. The drag disadvantage can be reduced by the use of a large spinner which would carry the cowl lines forward and toward the center in a smooth manner. Cooling air would be admitted through a hole in the spinner nose. Such a system would, however, reduce the amount of cooling air available at low speeds instead of increasing it; so blower blades could be built into the spinner to furnish the cooling air necessary for the low-speed flight conditions. The basic simplicity of the N.A.C.A. cowling is retained by this system in that the air is passed through the engine from front to rear. The only addition to the N.A.C.A. cowling is the spinner which can be justified if the drag is substantially reduced and the cooling at low speeds improved. The power expended to cool the engine will necessarily increase, but since the theoretical power required is ordinarily about 1 percent of the engine power, a relatively low efficiency may not be serious.

Blower 5 was built (see fig. 8) and tested as a result of the reasoning set forth above. The blower was designed on the theory that the cooling air would be drawn into the nose of the blower at relatively high velocity; energy would be added to the stream by the action of centrifugal force; and the air would be slowed down as much as possible by means of expanding passages so that the increase in energy would be manifested by an increase in pressure rather than velocity.

There seems to be no entirely satisfactory method for testing a blower of this type in model form because the cooling criteria, pressure, and volume only apply for conditions of fairly uniform pressure difference across the engine orifice plate and for conditions of flow which are free from angularities and turbulence. Heat transfer from a solid to a fluid is primarily a function of the local stream velocity at the surface, and any method or device which will result in increasing that local velocity will increase the cooling.

The exhaust from blower 5, which would be directed at the cylinder heads and barrels of an engine, was in the form of a continual series of high-speed jets which emerged from the blower compartments. The pressure surveys made of the stream behind the blower showed that there existed large pressure gradients in the radial and rotational directions and that the air particles traveled in paths of helices. This flow description fortunately is not applied as a means for aircraft propulsion, but in engine cooling for which angularity and velocity gradients may prove to be beneficial rather than detrimental. The cooling characteristics cannot be determined, therefore, by model tests with any degree of certainty.

Pressure, volume, power, and drag measurements were made, nevertheless, as a means for evaluating the aerodynamic qualities of blower 5. Considerable trouble was experienced, even then, in measuring the pressure and volume owing to the nature of the flow leaving the blower. It was found necessary to substitute a tail pipe exhausting beneath the wing for the normal exit slot in order that accurate flow measurements could be made. This tail pipe introduced additional complications because the true drag or thrust could not be measured directly. The tail-pipe cross-sectional area was purposely made small in order that the exit velocity would be fairly high so that accurate volume measurements could be made. This small tail pipe resulted in a high thrust for low V/nd conditions but at high values of V/nd the tail pipe was a source of drag. Had it been possible to make the tests with the normal exit slot, the thrust and drag difficulties would not have entered because the slot width could have been adjusted to obtain the best conditions for all values of V/nd. In practice the slot should be opened wide for low-speed conditions so that all the available energy is used for cooling purposes rather than creating thrust. The slot should be nearly closed for high speeds so that the added

pressure arising from the forward speed is used at the exit slot to accelerate the cooling air back to free air velocity. The blower should add only the energy necessary to overcome the internal flow losses arising from cooling the engine, etc.

Tail-pipe correction.- An attempt has been made to reduce the errors arising from the tail-pipe method by computing what the pressure and thrust would have been at all times had the tail-pipe area been such that the exhaust velocity were equal to the free stream velocity. This correction was made by the use of the relation, $T=V_pA_p\rho(V-V_p)$, where

T is the thrust,

V_p, the measured velocity in the tail pipe,

A_p, the area of the tail pipe, and

V, the free stream velocity.

In applying this correction it is assumed that A_p is adjusted so that V_p equals V, then the thrust from the exhaust equals zero. The difference in the pressure obtained by this adjustment is credited to the pressure across the engine orifice plate. The result of this correction is to translate thrust into pressure across the engine orifice plate.

This correction is not entirely satisfactory because the changes in the exit area result in changes in the pressure across the orifice plate but there is no corresponding change in volume, which means that the effective orifice area is also changing. Even values of $\frac{K_3}{\sqrt{2K_1}}$ (this ratio defines the orifice area for a given blower) are superposed on the corrected curves in order to identify the equivalent orifice sizes for the different test conditions. Another difficulty encountered arises from the drag of the tail pipe. At high values of V/nd it is assumed that the tail-pipe area is decreased but no allowance is made for any decrease in the drag which would naturally result. Consequently, the efficiency is lower than it should be.

Blower 5 results.- The test results for blower 5 are given in figures 46 to 53. These figures include the re-

sults obtained by both methods of computation. The results are quite similar to those obtained with blowers 2 and 3 tested in conjunction with the wing-duct system (see reference 2) in that the pressure volume and power coefficients are about the same. The efficiencies computed for blower 5 are less than would be desired in that they range from 15 to 50 percent. (See figs. 52 and 53.) The efficiency is about doubled at zero V/nd by the correction applied for the effect of the tail pipe. This means that about half of the useful energy was being expended to produce thrust, and did not contribute to the efficiency.

The effect of the tail-pipe correction is to increase the pressures at low values of V/nd and reduce them at high values (see figs. 46 and 47), resulting in more uniform pressures over the flight range. The increment thrust or drag is reduced to about zero for the entire flight range. (See figs. 50 and 51.)

<u>Drag</u>.- The drag coefficient obtained for the streamline body shown in figure 9 is 0.039; that measured for blower 5 was 0.045 (no air flowing). This agrees reasonably well relatively with results obtained in the 8-foot high-speed tunnel which showed an increase in drag of only 4 percent due to a corresponding hole in the nose of a streamline body. Various tests of the drag of N.A.C.A. cowled nacelles in the presence of wings indicate the drag coefficient to range from about 0.06 to 0.09 for corresponding set-ups.

<u>Efficiency</u>.- An efficiency of over 50 percent was expected from blower 5. That the efficiency was less than this may be accounted for by the type of flow emerging from the blower. Extensive surveys made in the exhaust showed that the blower compartments were not filling properly. The flow was separating from one side of each compartment, and to a certain extent from the inner surfaces. There are two factors which probably caused the separation noted: (1) too great an expansion in each compartment, and (2) too rapid turning of the air within the compartments. The exit area of each compartment was 1.8 times the entrance area. This expanding rate is not considered excessive if the conditions are fairly ideal but the conditions in this blower probably are not ideal for rapid efficient expansion. The cooling air is forced to make three turns and is acted upon by the centrifugal force due to the blower rotation in addition. Each turn results in

centrifugal force tending to throw the particles of air away from the center of curvature which may act to accelerate separation from the walls. Once separation starts at any point further expansion is not likely.

A cure for the apparent deficiencies of blower 5 appears to consist of reducing the rate of expansion in the compartments and reducing the curvature of the passages until separation does not exist. It seems clear that if the internal losses are reduced to that of pure friction (turbulent boundary layer), the efficiency will be considerably higher than obtained in these tests.

Although higher efficiencies are obviously desired and can be obtained no doubt, efficiencies of the order of 30 percent are not considered too low to render the scheme useless, because the theoretical power required to cool most engines is only of the order of 1 percent of the power of the engine. The net power required for cooling with blower 5 would be about 3 percent as compared to about 1.5 percent for a conventional cowling, assuming pumping and propeller efficiencies of 80 percent each. Differences in drag overshadow this difference in cooling power, however, because it is estimated that for certain high-speed airplanes savings of the order of 5 to 15 percent of the engine power can be saved through better streamlining of the nose.

Design considerations.- The only definite instructions regarding the design of blower 5 which can be given at the present time include only those relating to the design diameter. It is clear that, if the internal arrangement of a blower is made similar, but in a different size, the coefficients will be the same. The pressure and volume desired for any given condition are determined by the design diameter and may be computed directly. Other design factors such as the relative area of the inlet opening to the exhaust area, the shapes of the passages, and the size of the entrance opening with respect to the cowling diameter are all important no doubt; but no data are available at the present time covering any variations of these elements. The present tests indicate that blower 5 can be improved by modifying the passages so that the flow will not separate from the surfaces.

Another blower is being built for tests with an engine in which the passages are modified in such ways as to reduce the possibilities of flow separation. The expansion

rate is reduced, the blower is made longer in relation to the diameter, and the blades are developed on large curves so that the air will be scooped up with as little shock as possible. It is believed that these changes will result in a definite higher efficiency. The cooling characteristics with this type of blower will be studied at the same time.

CONCLUDING REMARKS

These preliminary tests with blowers mounted on or in propeller spinners for the purpose of cooling radial engines indicate the following generalities:

The use of side air-intake entrances with blowers provides means for obtaining engine cooling which is substantially independent of the speed of the aircraft. The maximum efficiency obtained with the side-entrance-blower system was about 70 percent, which occurred at a fairly low V/nd value. At high V/nd values the efficiencies were less than those obtained at the low values because the side entrances contributed drag when air was allowed to spill from the openings. The drag of the side entrances contributed little if any to the nacelle drag when the openings were covered. The lowest basic side-entrance nacelle drag recorded was the same as for a well-streamlined body, which was substantially less than for a conventional cowling, as determined in a previous investigation. (See reference 1.) The low drag of this cowling cannot be realized at high speeds unless means are found for eliminating the drag due to the air spilling from the side-entrance ducts. This problem, which had not clearly crystallized until after the present tests were completed, is one involving the shapes of the entrances and guide vanes and the size of the openings relative to the amount of air entering. Further work is necessary on the subject to clear up the problem.

A cowling incorporating a large blower spinner provided with internal passages for the cooling air to enter through the nose showed considerable promise as a means for obtaining adequate ground cooling and low drag. The efficiency of the first model blower did not come up to expectations, however, as the values were less than 50 percent. A pressure survey in the exhaust of the blower indicated the reason for the poor efficiencies to be separation of flow from the passage walls, which indicates

that the expansion rate of the air was too high considering the amount of turning required of the air. The pressure survey also indicated that this type of blower probably would be very effective in cooling the fronts of the cylinders of an engine because the high velocity exhaust stream would be effective in scouring the dead air from the fin surfaces. An improved blower is being built for operation with an engine for which a higher efficiency is expected and with which the cooling characteristics will be studied.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., June 1, 1939.

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#117 2. Biermann, David, and Valentine, E. Floyd: Preliminary Tests of Blowers of Three Designs Operating in Conjunction with a Wing-Duct Cooling System for Radial Engines. N.A.C.A. confidential report, April 17, 1939.

#95

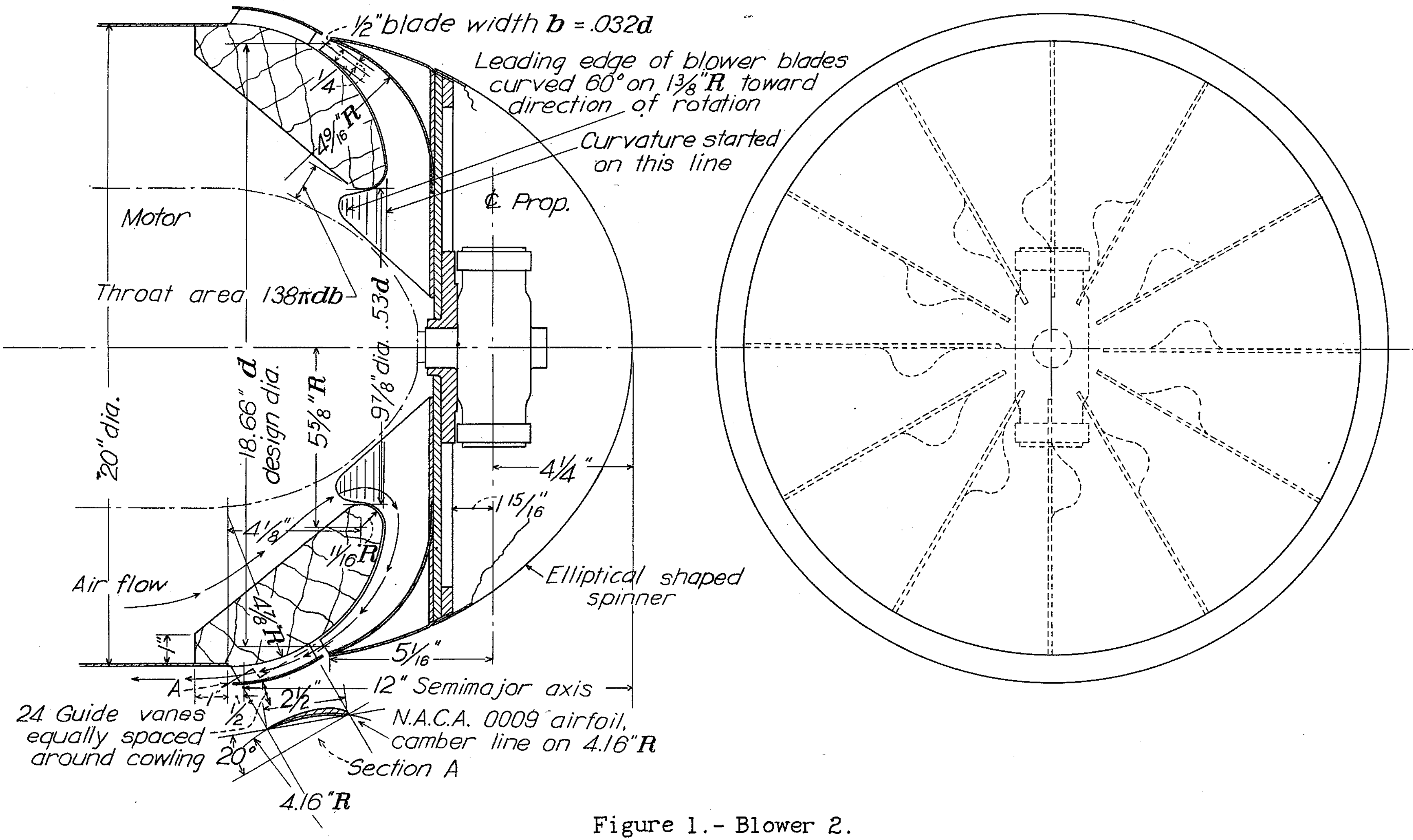

Figure 1.- Blower 2.

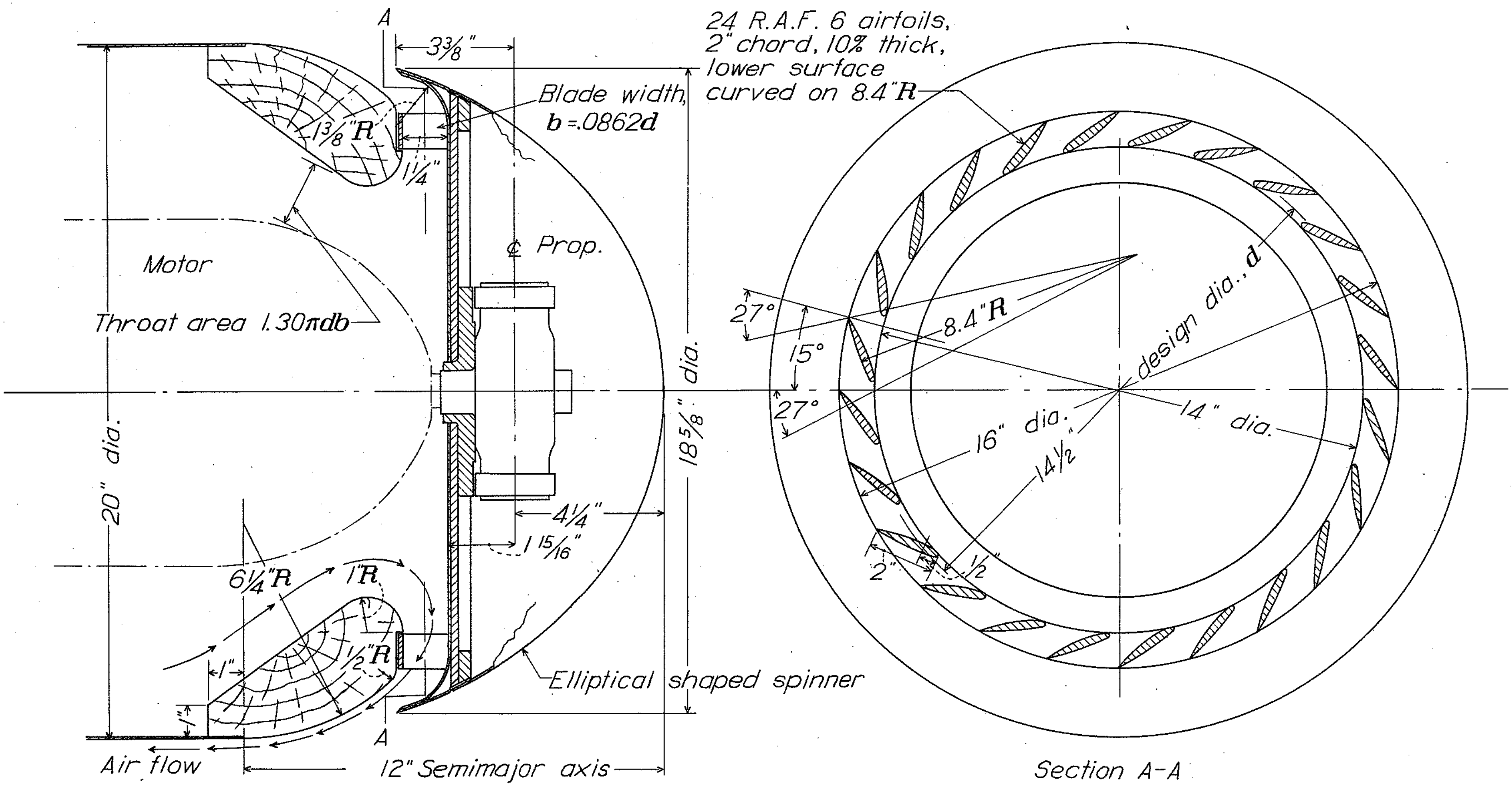

Figure 2.- Blower 4.

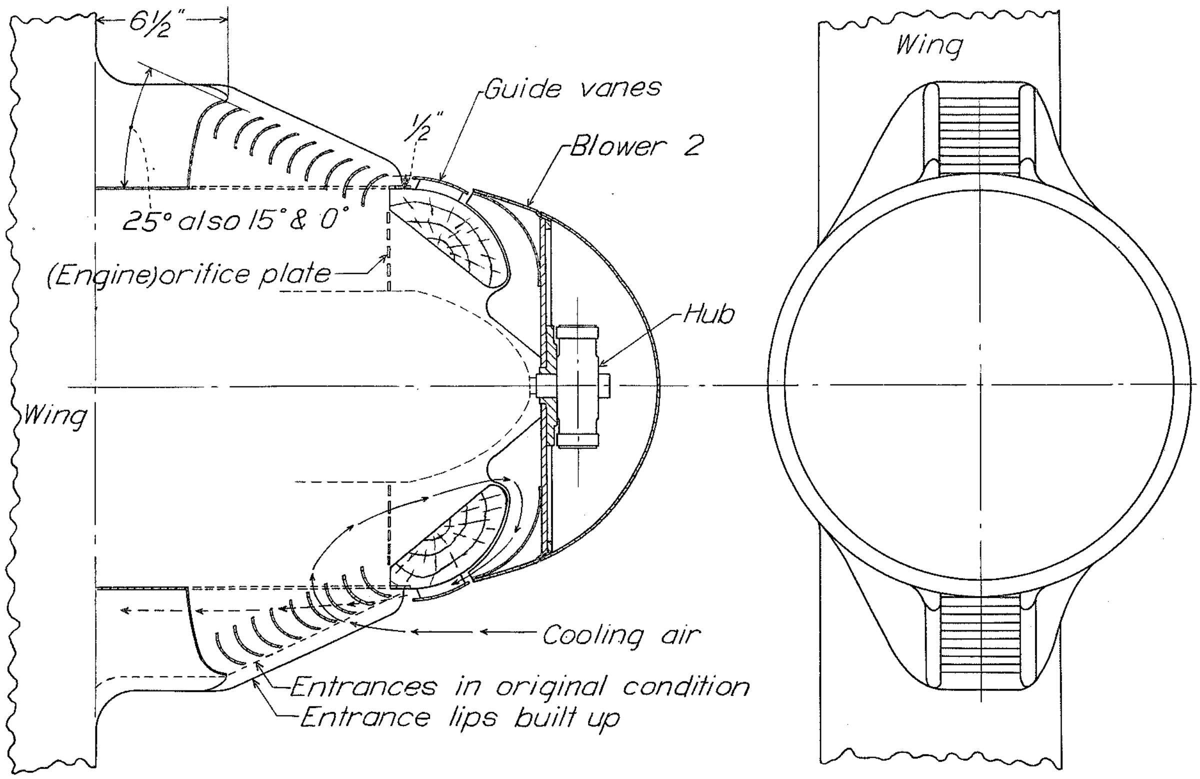

Figure 3.- Side-entrance ducts in front position.

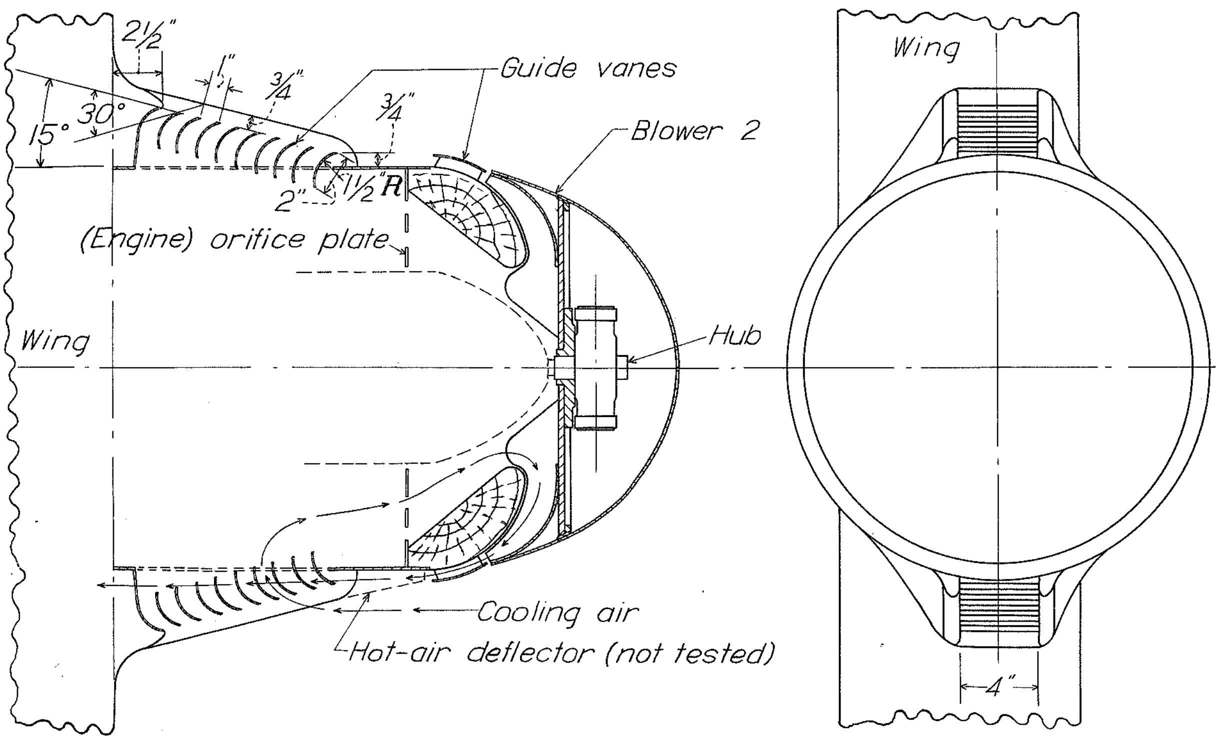

Figure 4.- Side-entrance ducts in rear position.

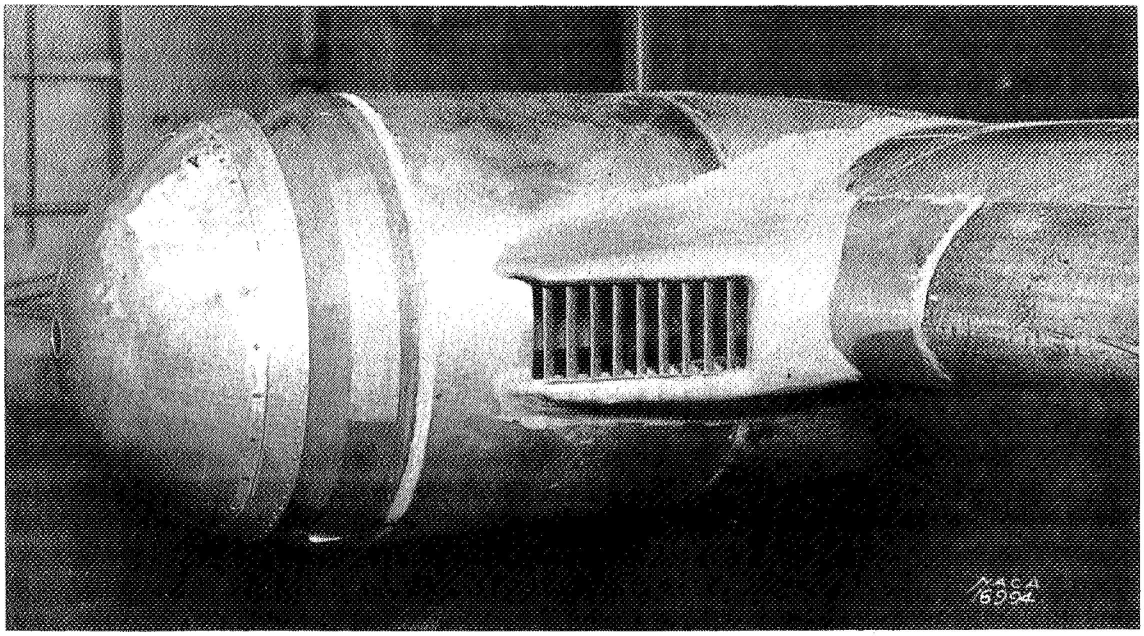

Figure 5.- Side entrance in rear position. Blower 4.

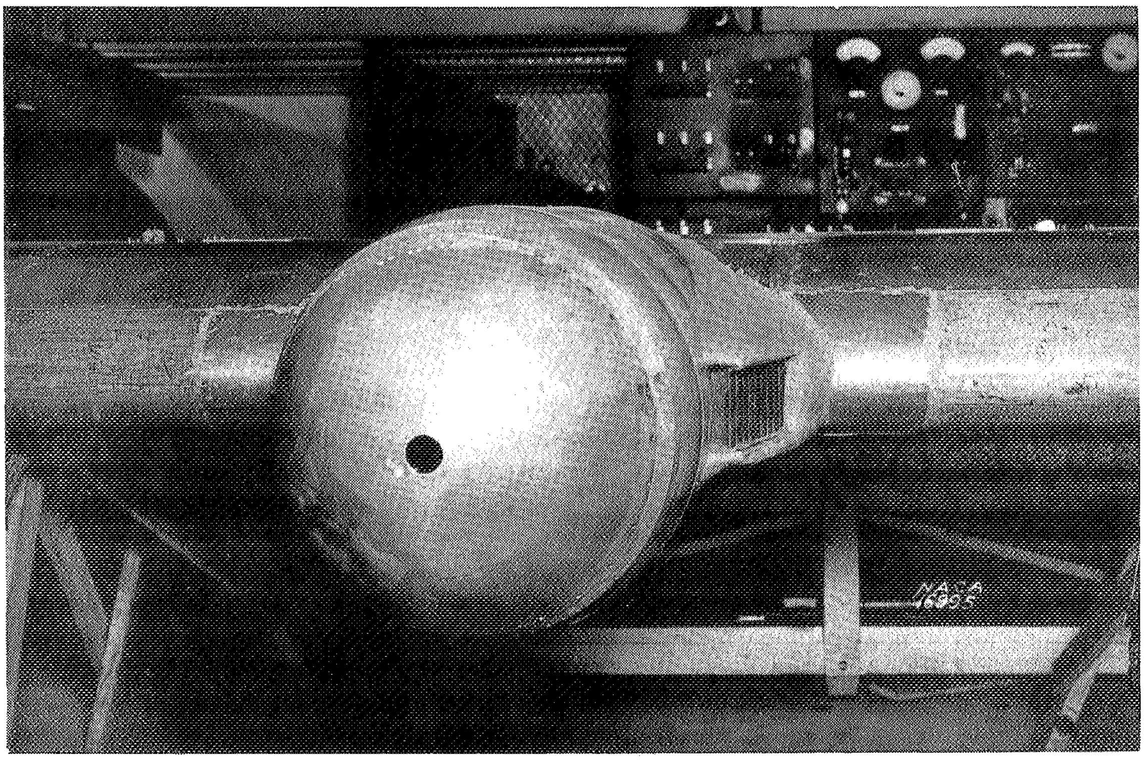

Figure 6.- Side entrance in rear position. Blower 4.

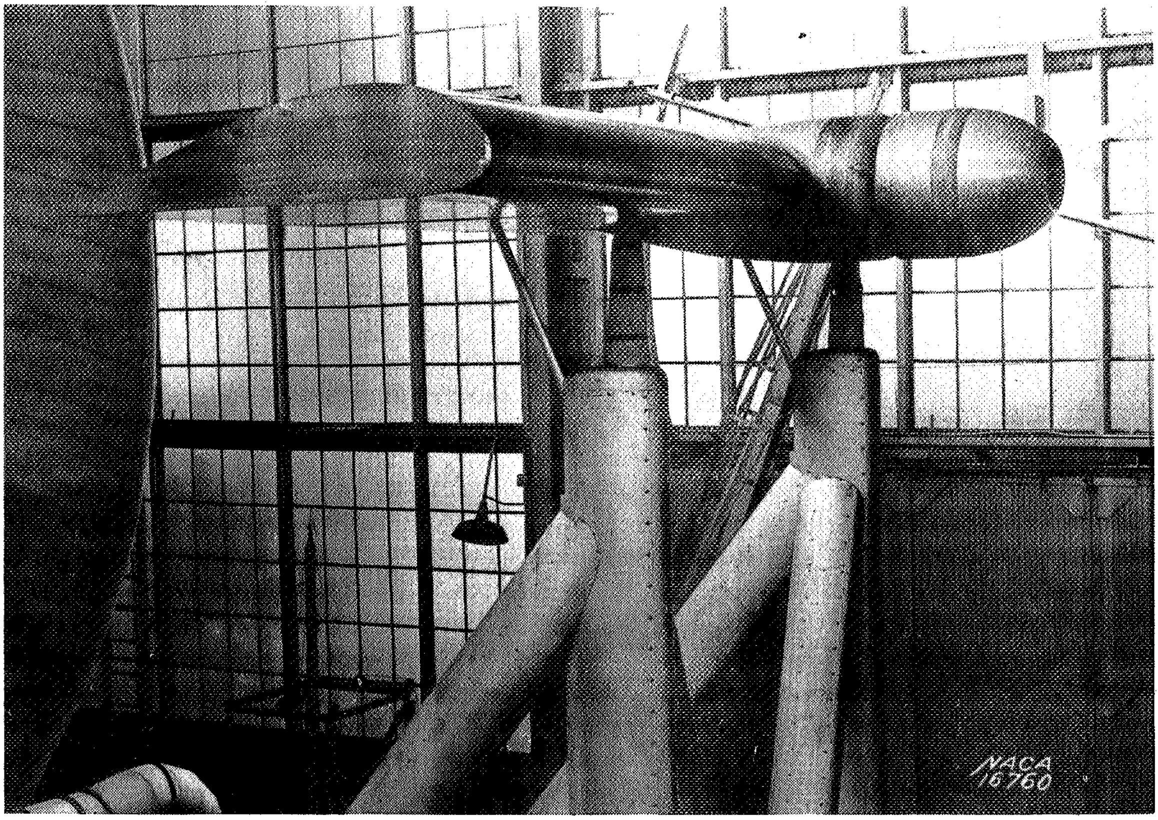

Figure 7.- Blower 6.

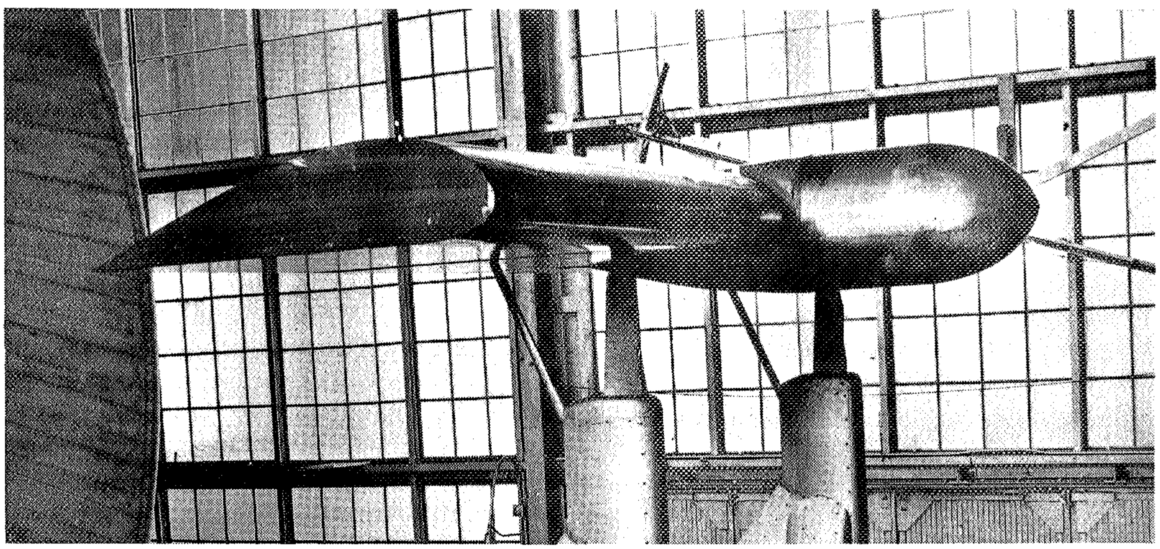

Figure 9.- Streamline body.

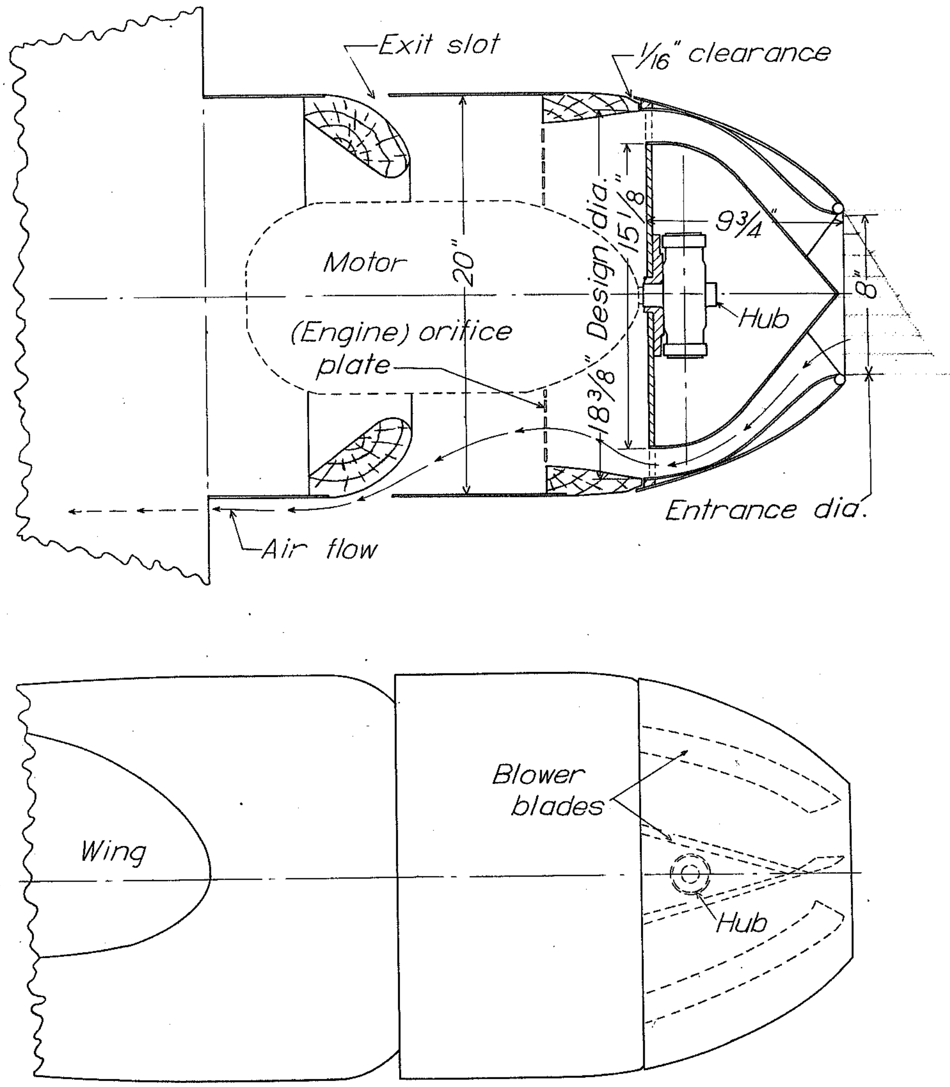

Figure 8.- Blower 5.

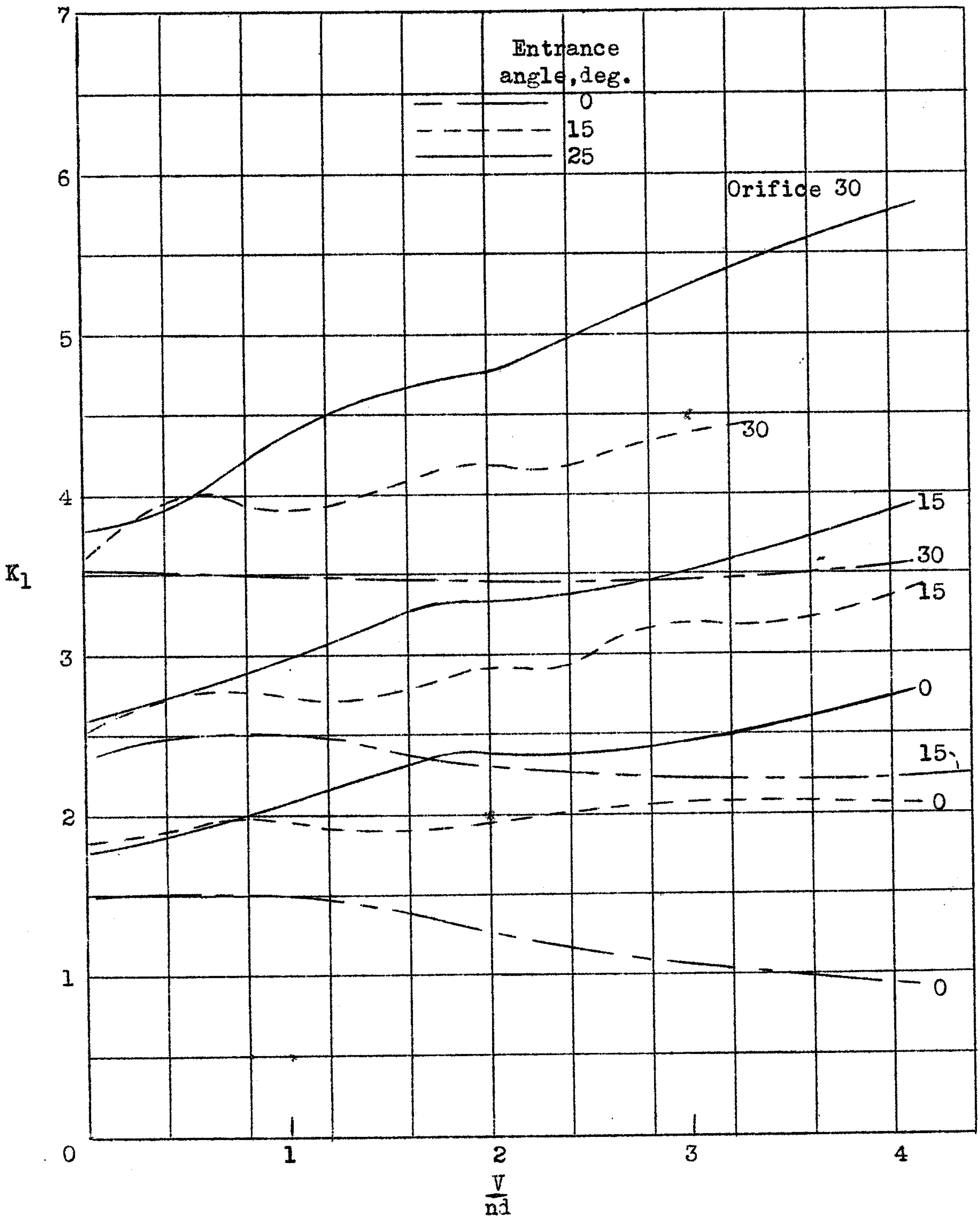

Figure 10.- Pressure coefficient. Blower 2. Side entrances in front position.

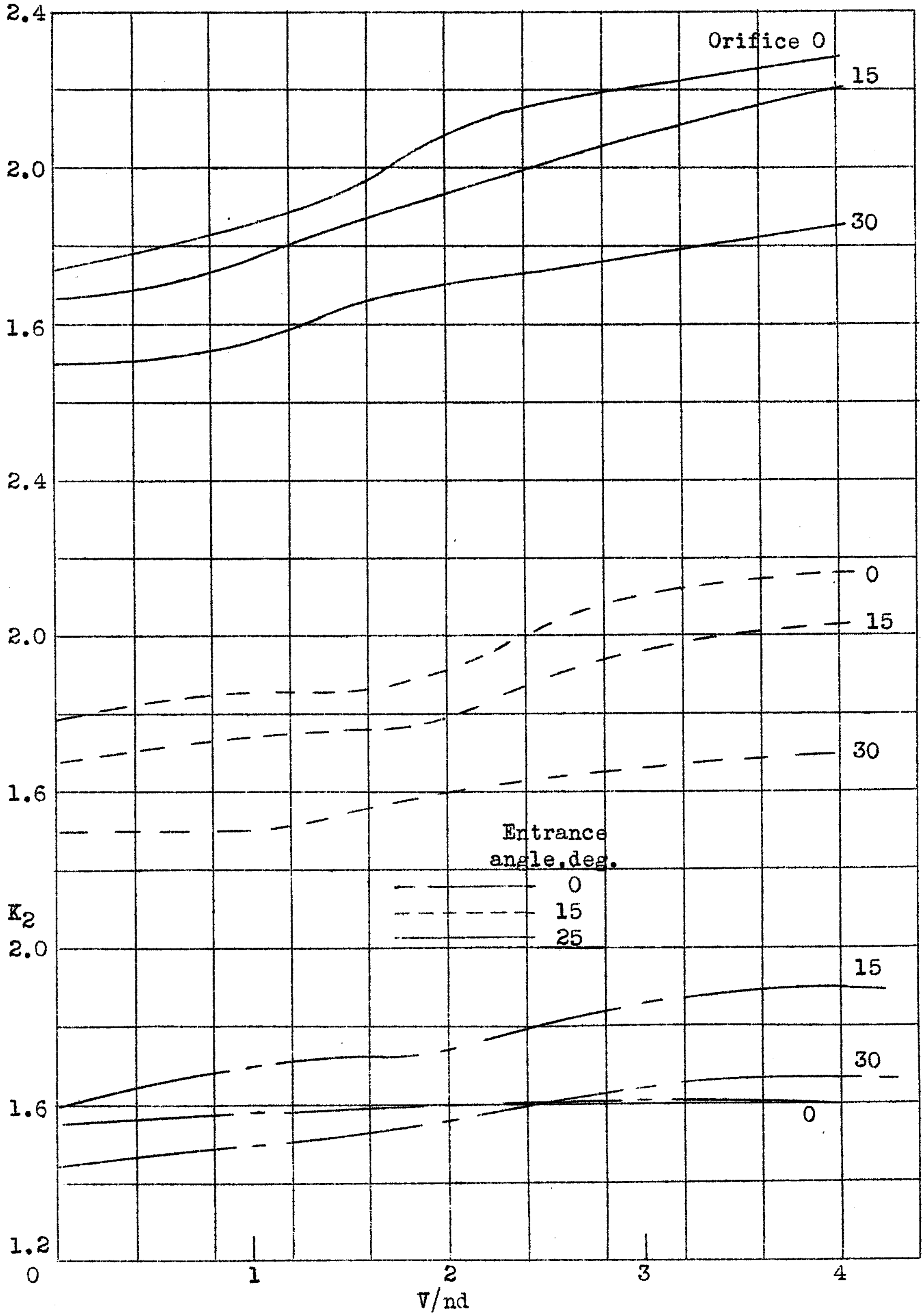

Figure 11.- Power coefficient.Blower 2. Side entrances in front position.

N.A.C.A. Fig.12

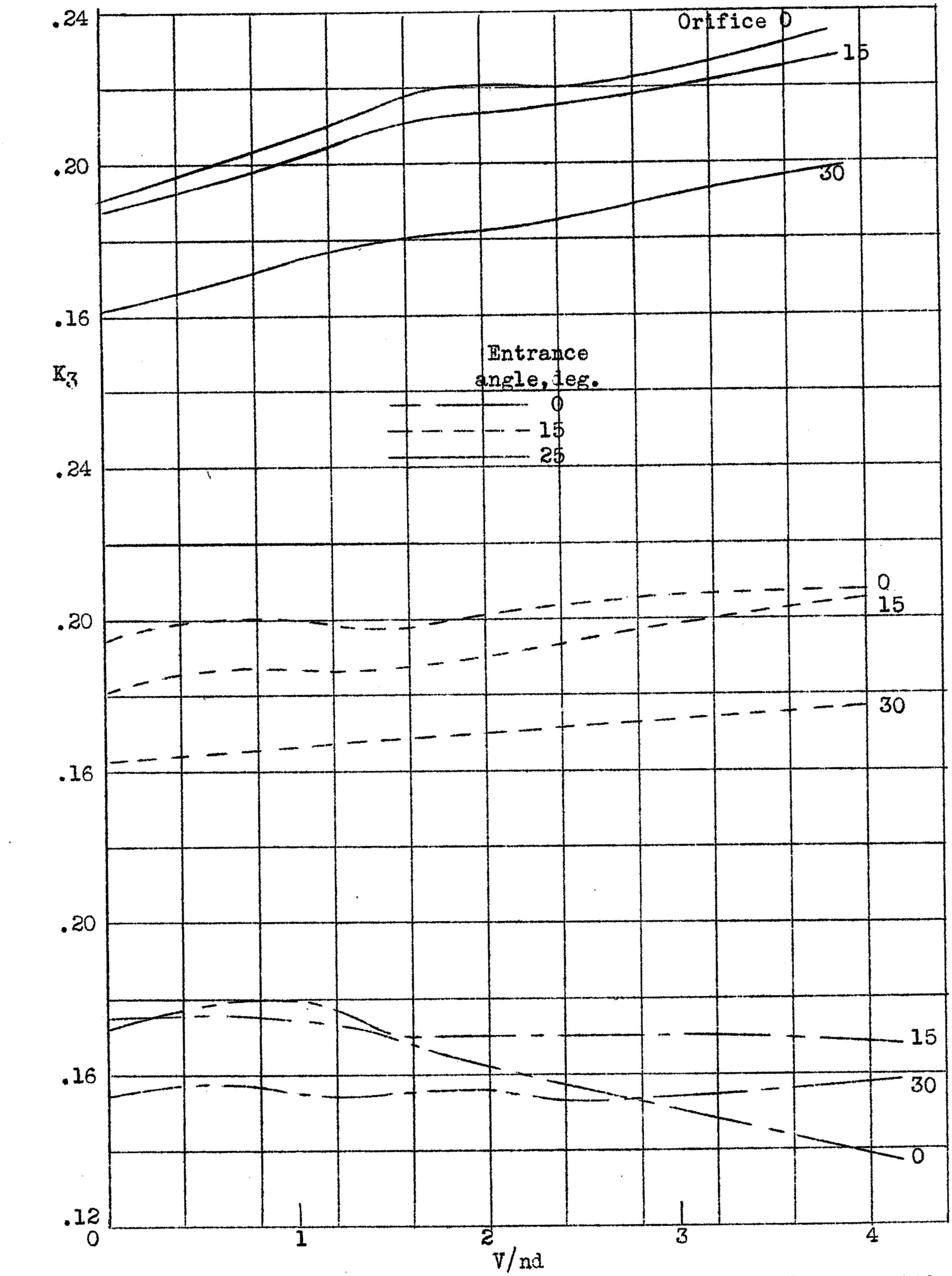

Figure 12.- Volume coefficient. Blower 2. Side entrances in front position.

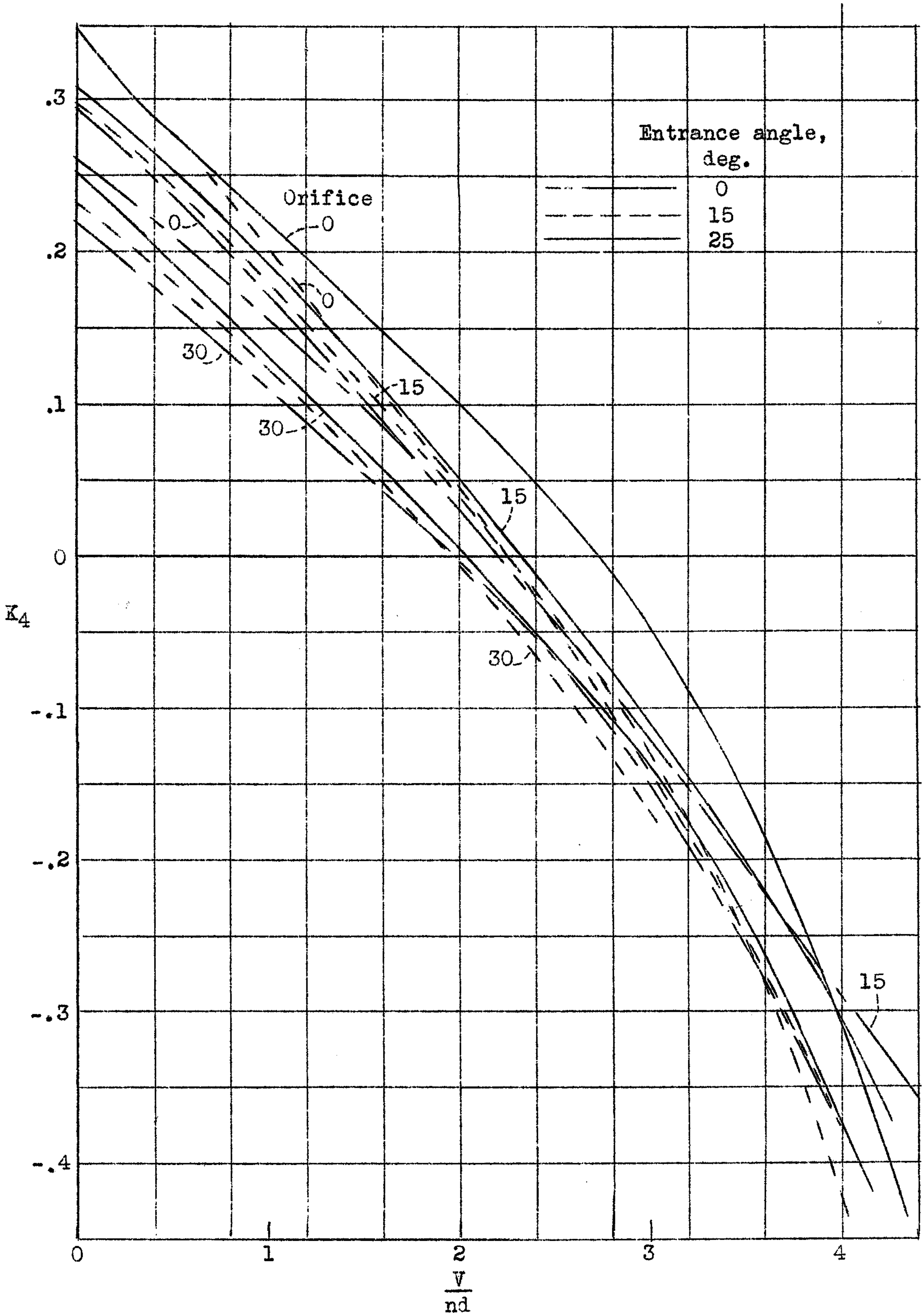

Figure 13.- Thrust coefficient. Blower 2. Side entrances in front position.

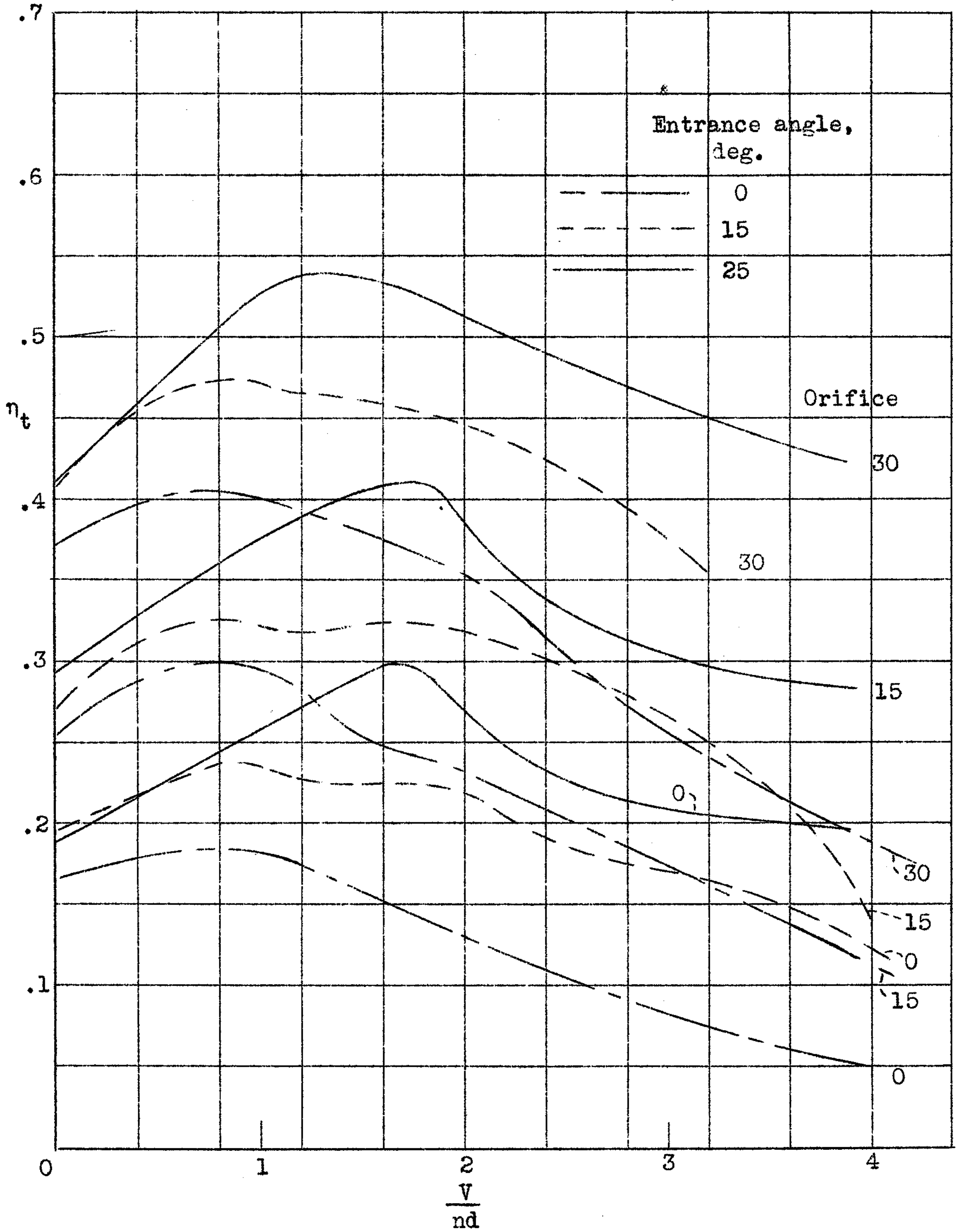

Figure 14.- Efficiency. Blower 2, Side entrances in front position.

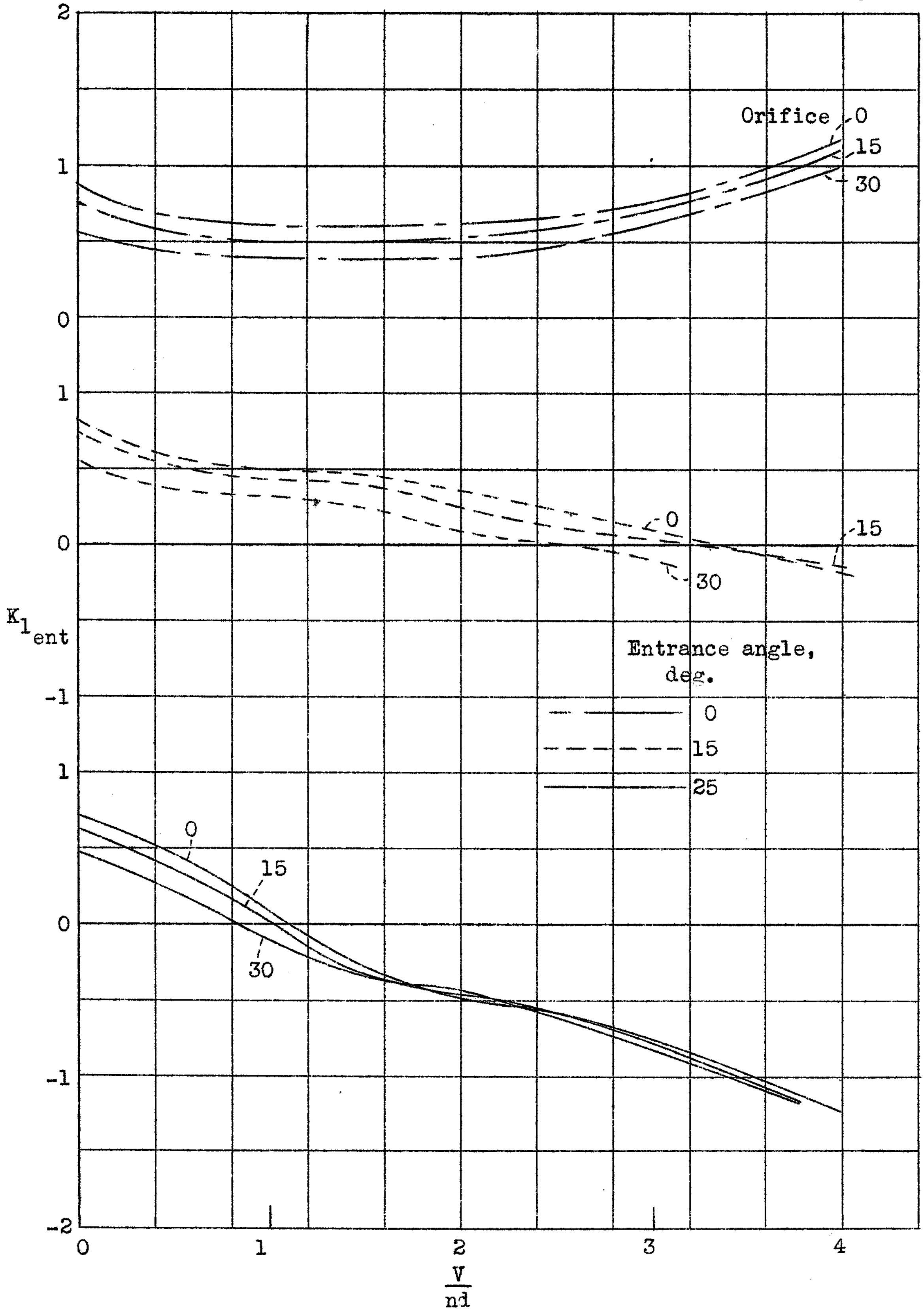

Figure 15.- Entrance pressure coefficient. Blower 2. Side entrances in front position.

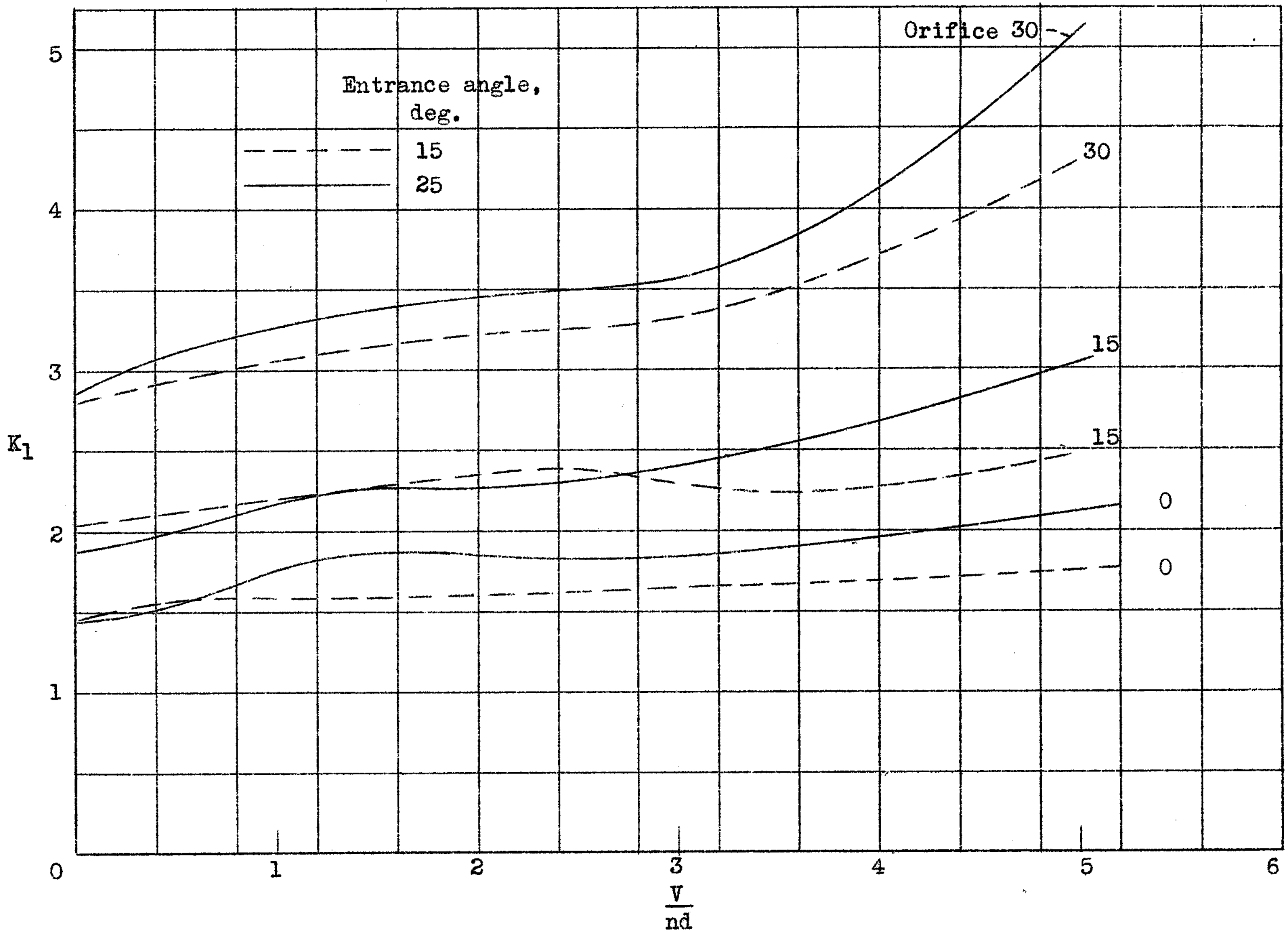

Figure 16.- Pressure coefficient. Blower 4. Side entrances in front position.

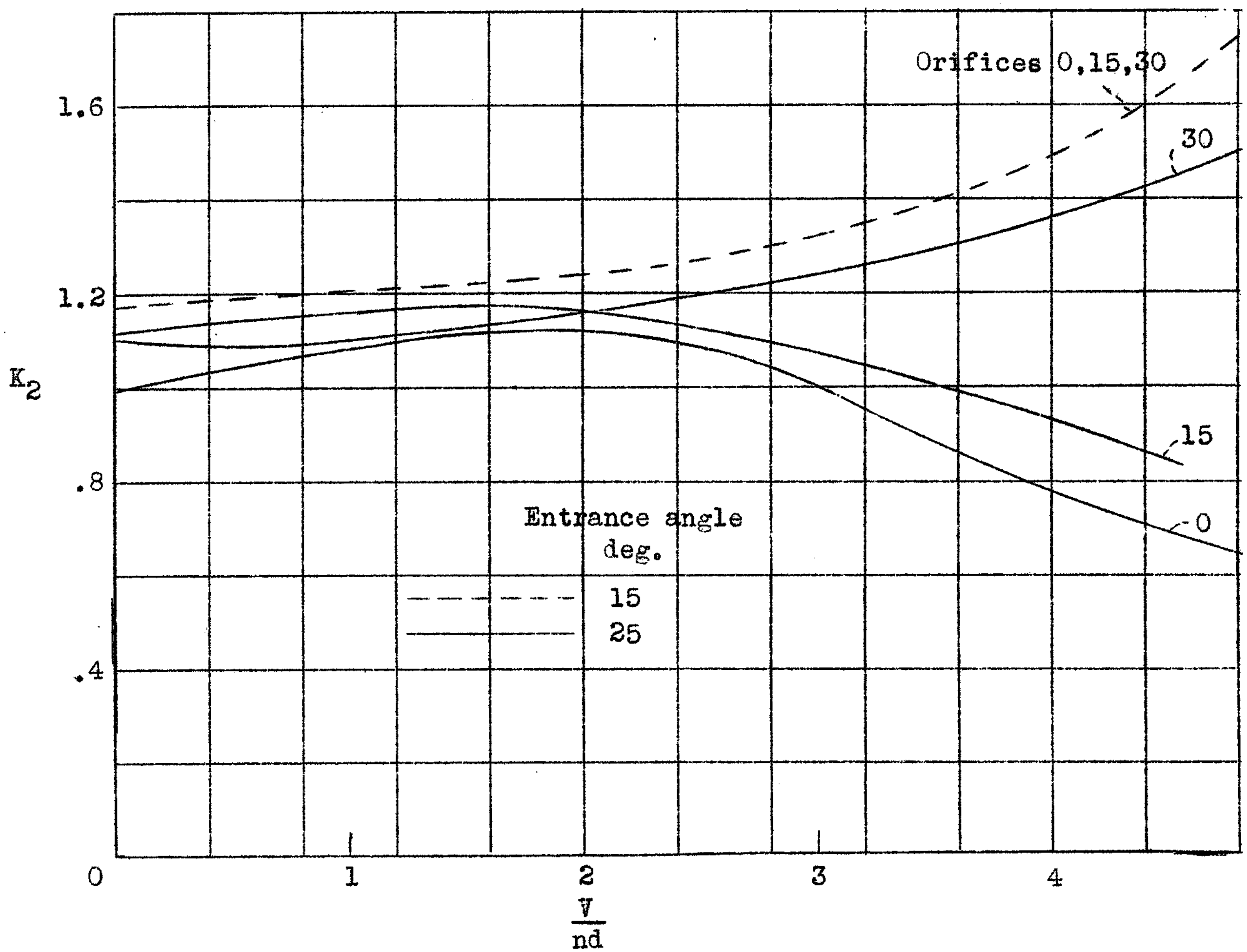

Figure 17.- Power coefficient. Blower 4. Side entrances in front position

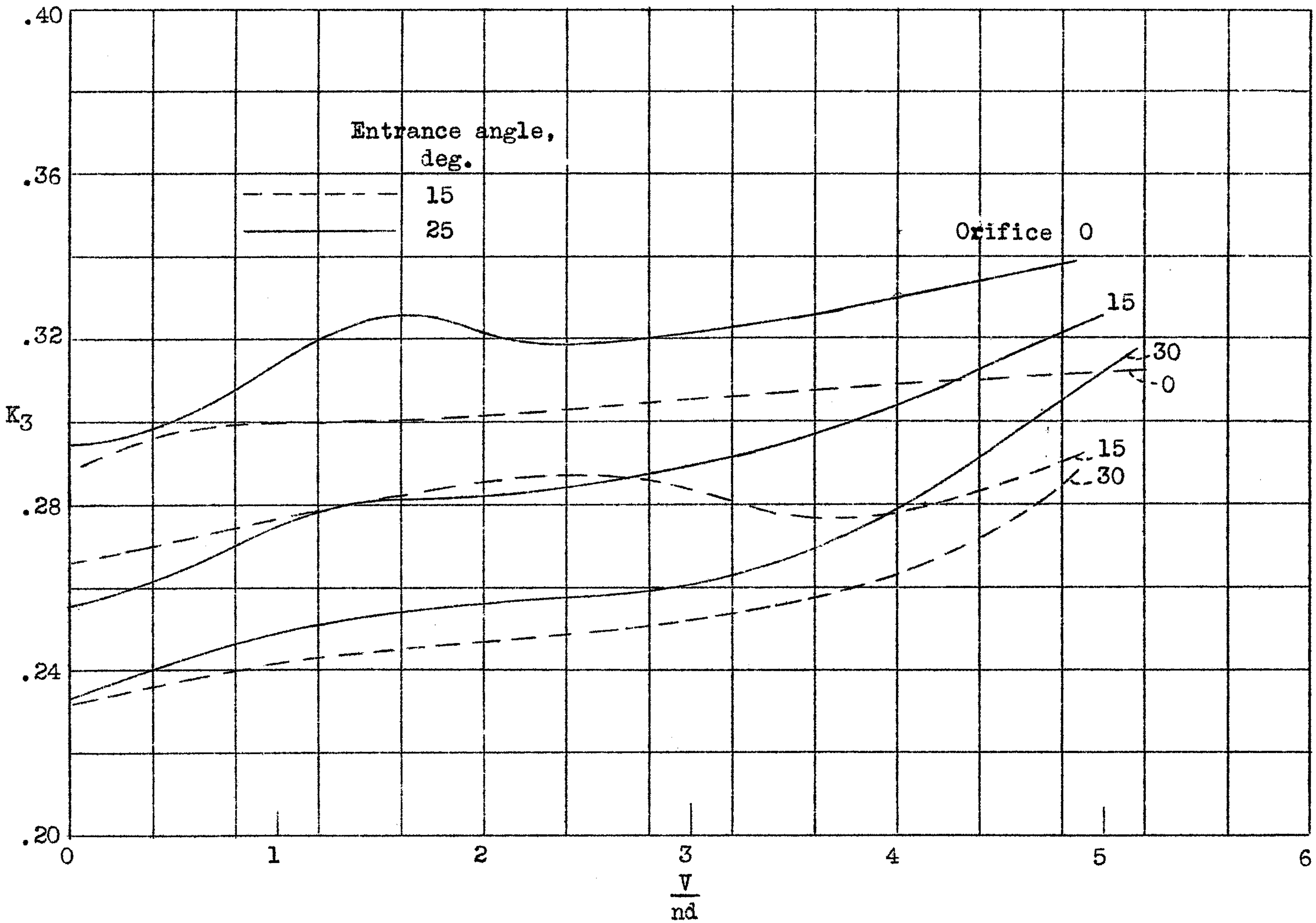

Figure 18.- Volume coefficient. Blower 4. Side entrances in front position

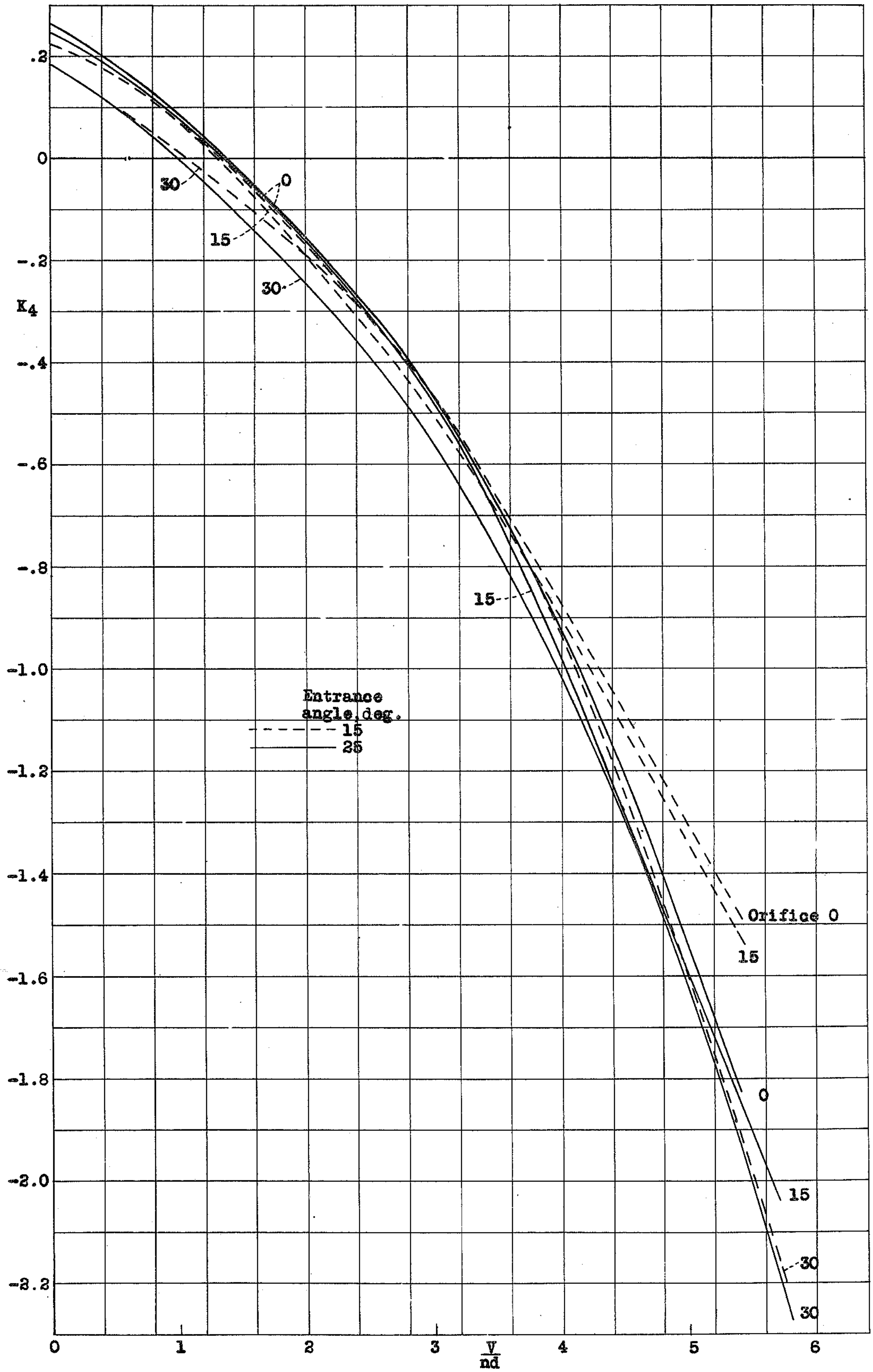

Figure 19.- Thrust coefficient. Blower 4. Side entrances in front position.

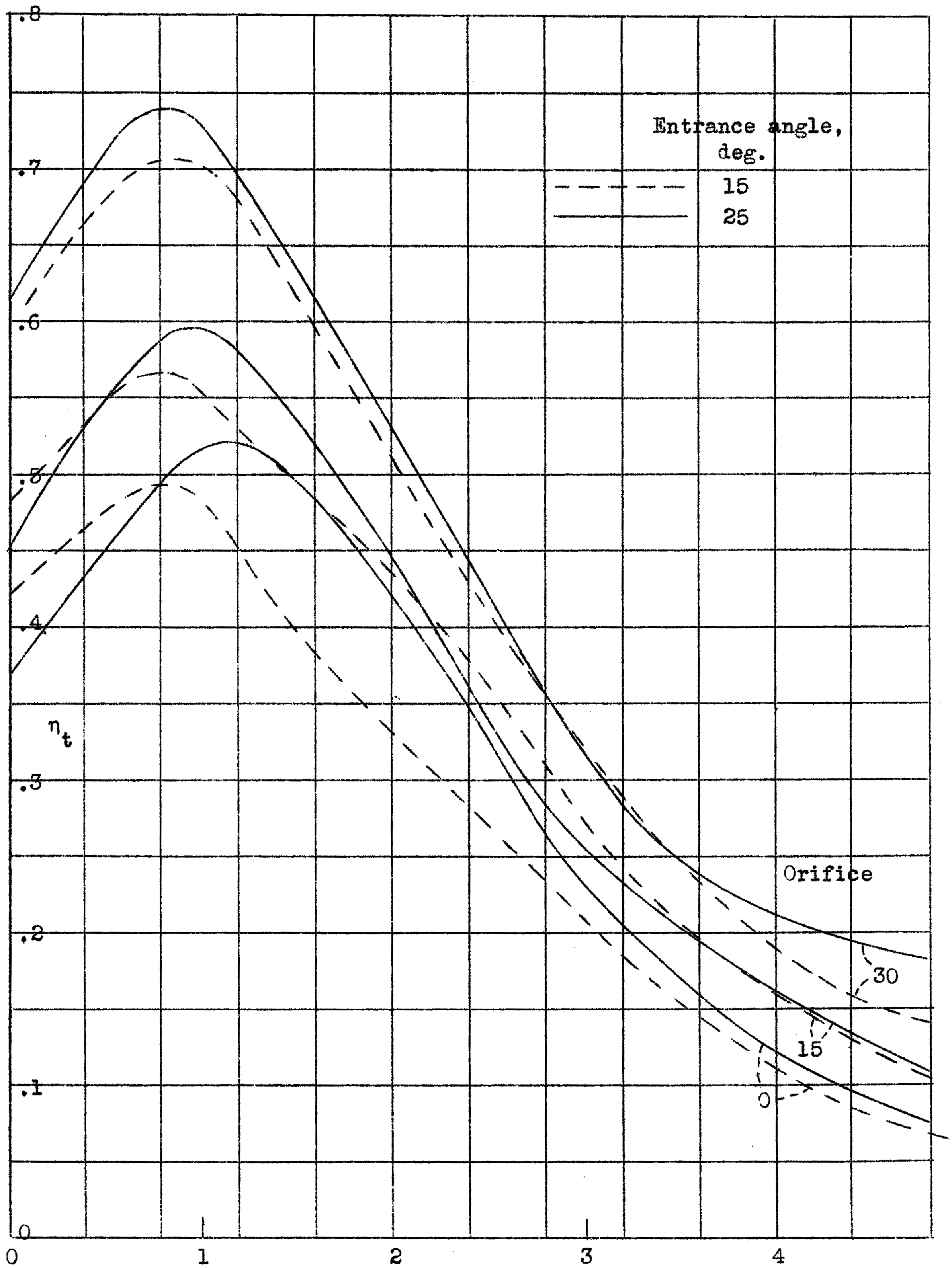

Figure 20.- Efficiency. Blower 4. Side entrances in front position.

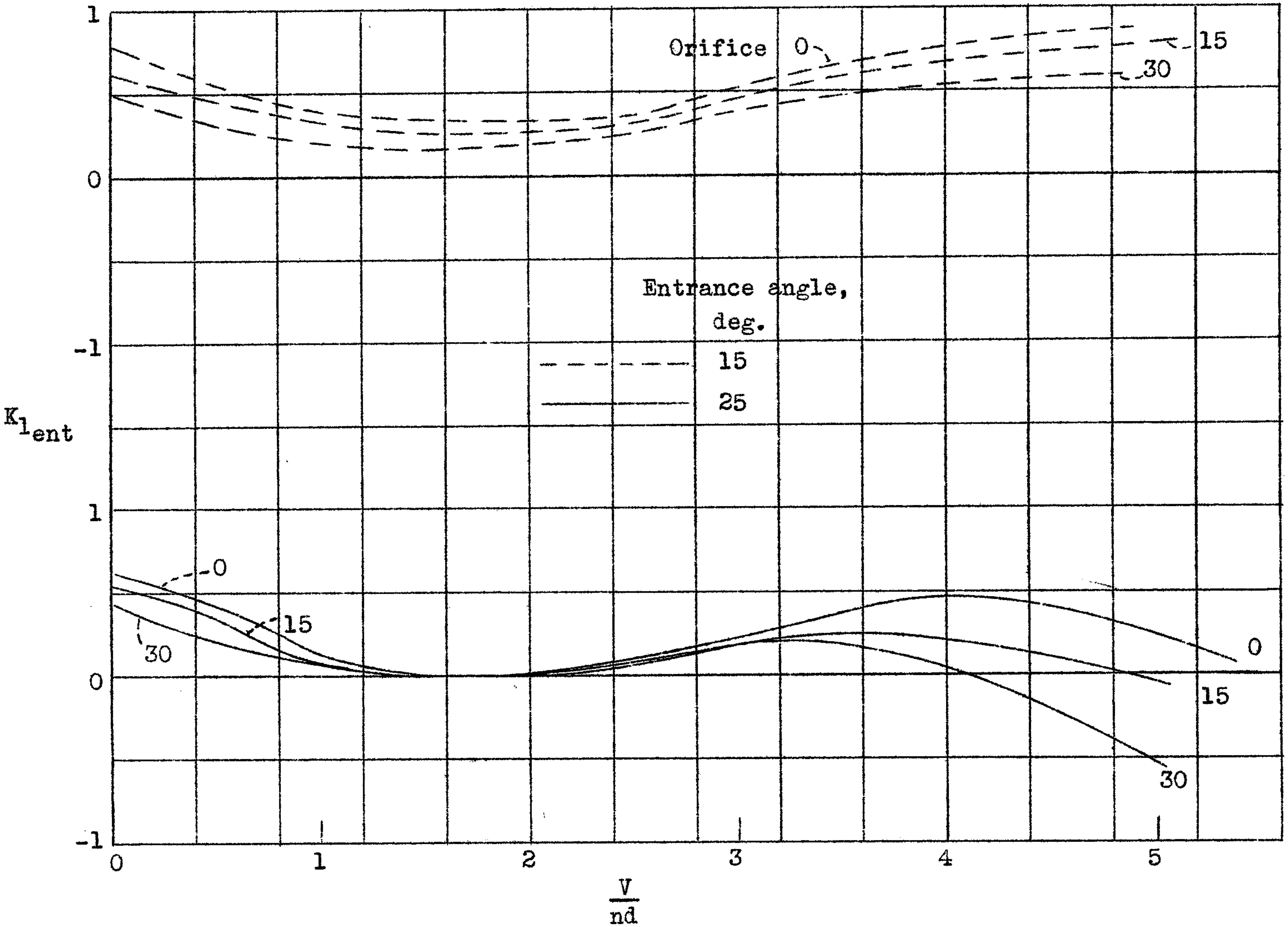

Figure 21.- Entrance pressure coefficient. Blower 4. Side entrances in front position.

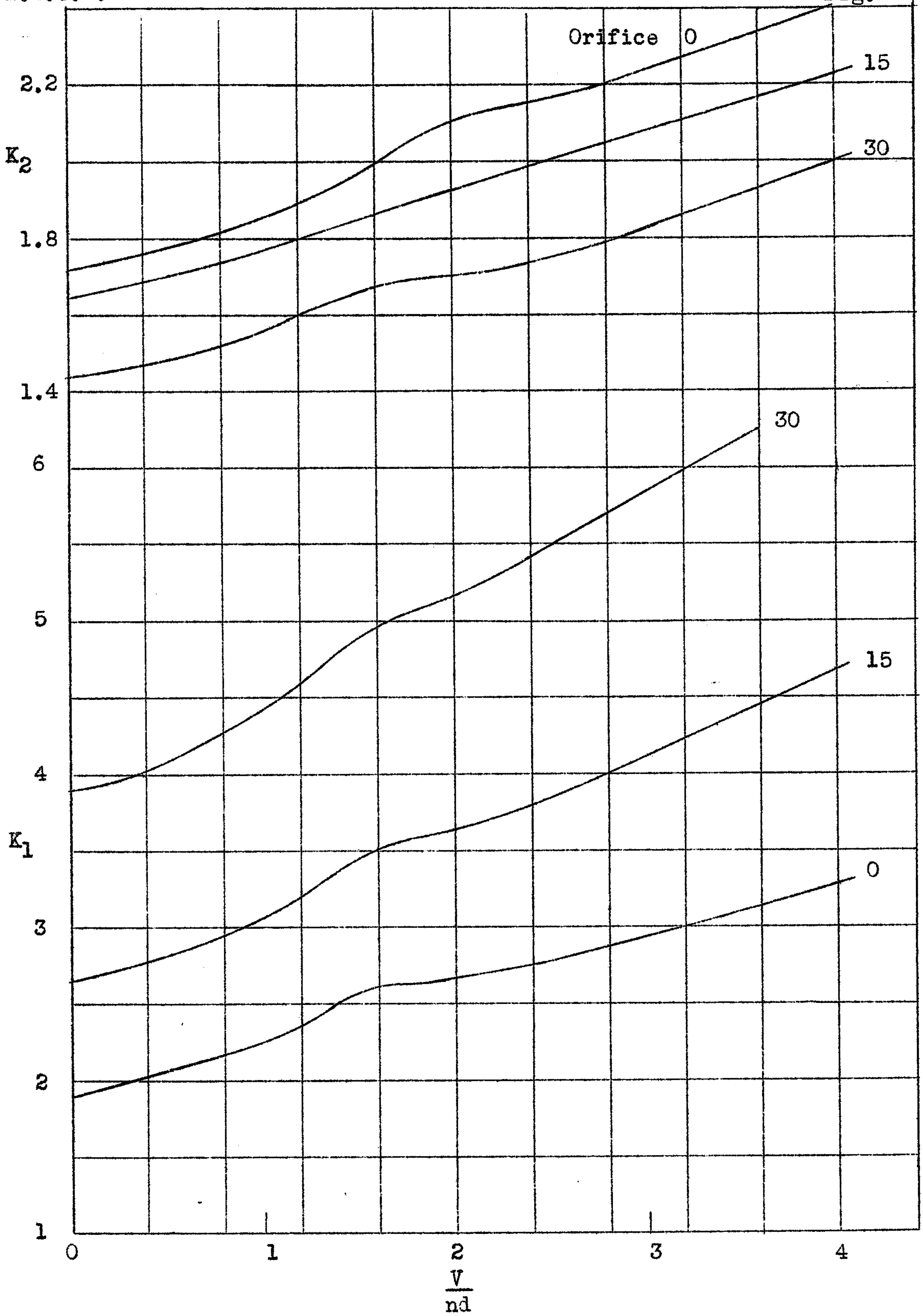

Figure 22.- Pressure and power coefficients. Blower 2. Side entrances in front position. Entrance lips built up.

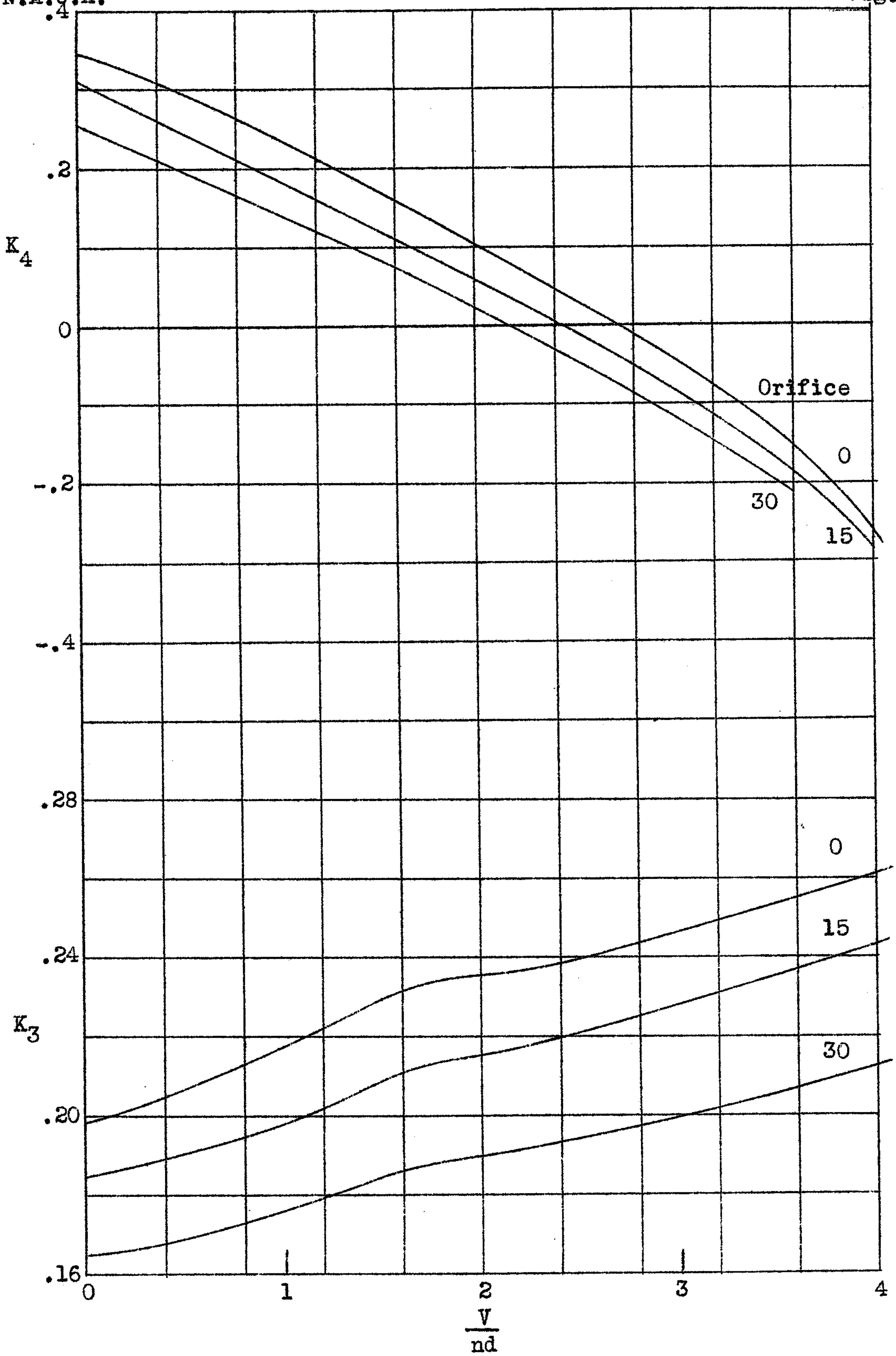

Figure 23.- Volume and thrust coefficients. Blower 2, Side entrances in front position. Entrance lips built up.

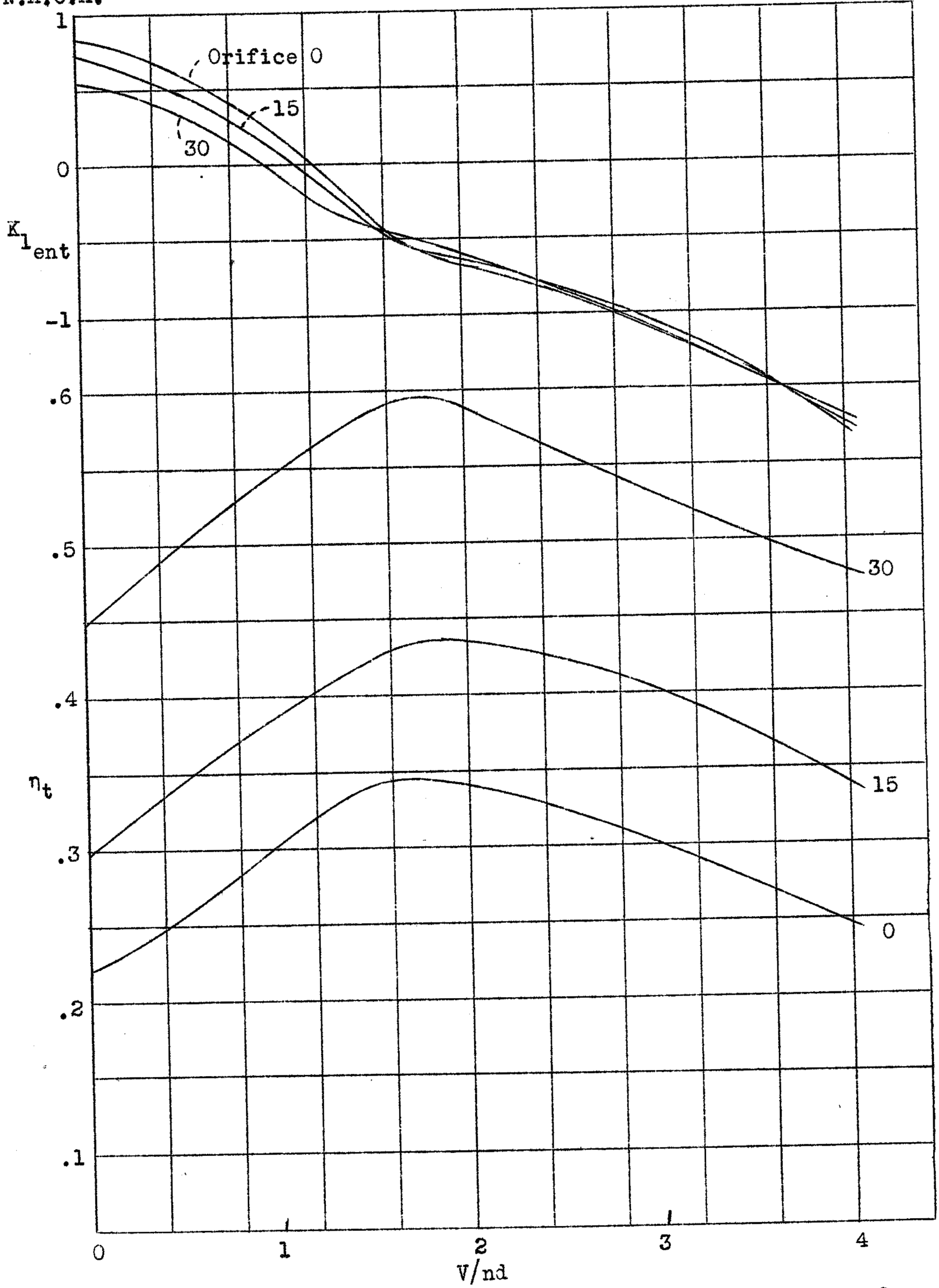

Figure 24.- Efficiency and entrance pressure coefficient. Blower 2. Side entrances in front position. Entrance lips built up.

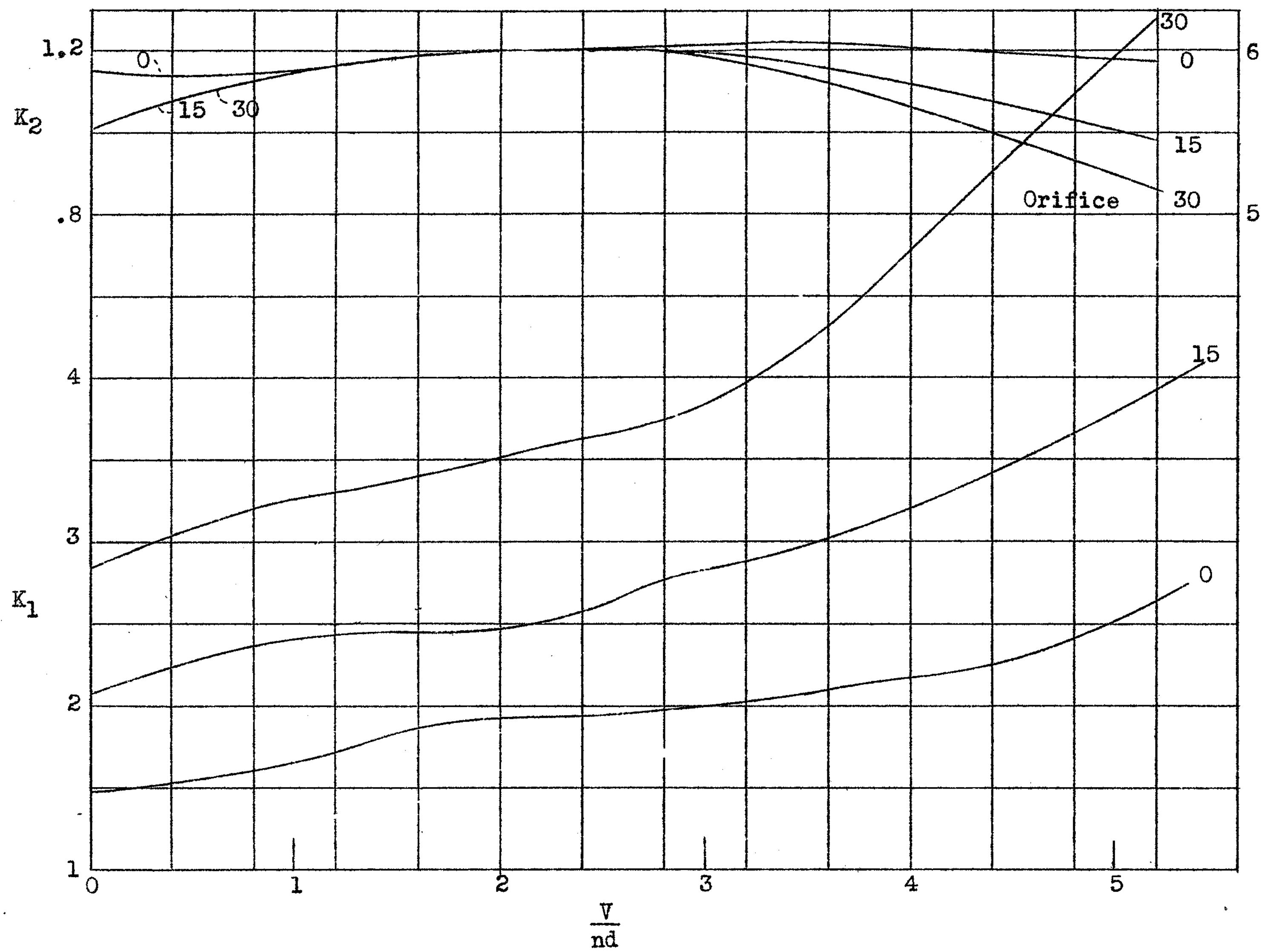

Figure 25.- Pressure and power coefficients. Blower 4. Side entrances in front position. Entrance lips built up.

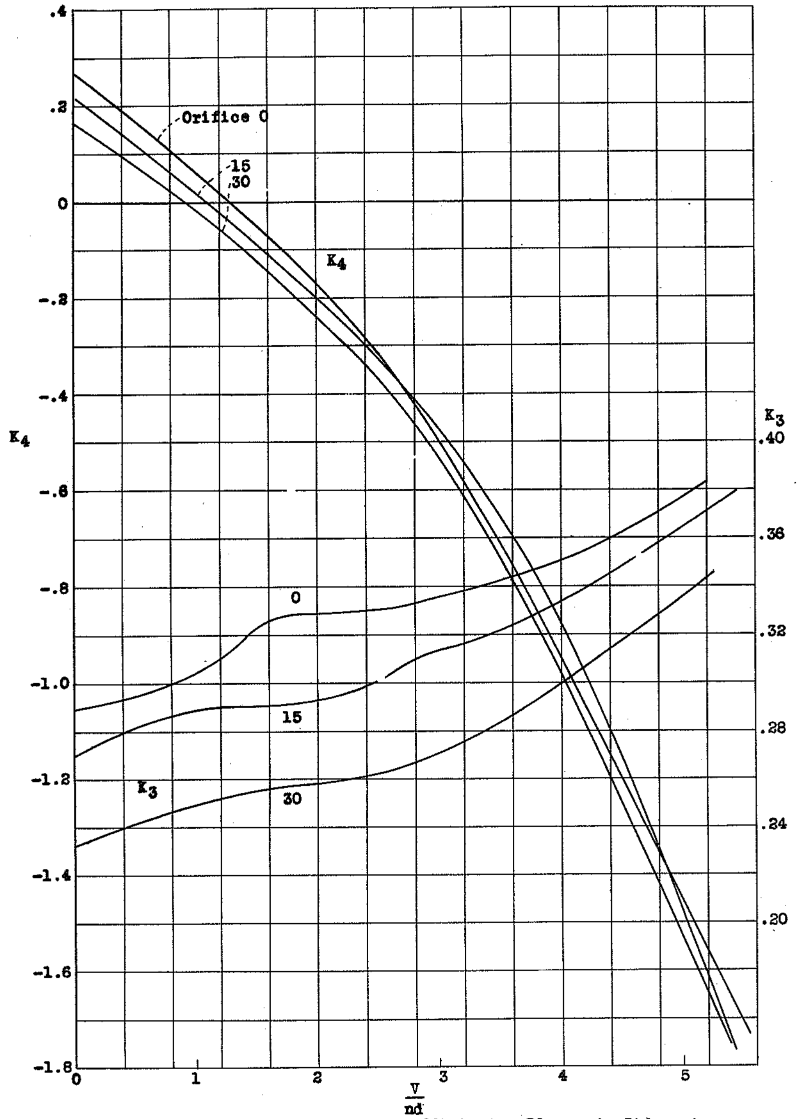

Figure 26.- Pressure and thrust coefficients. Blower 4. Side entrances in front position. Entrance lips built up.

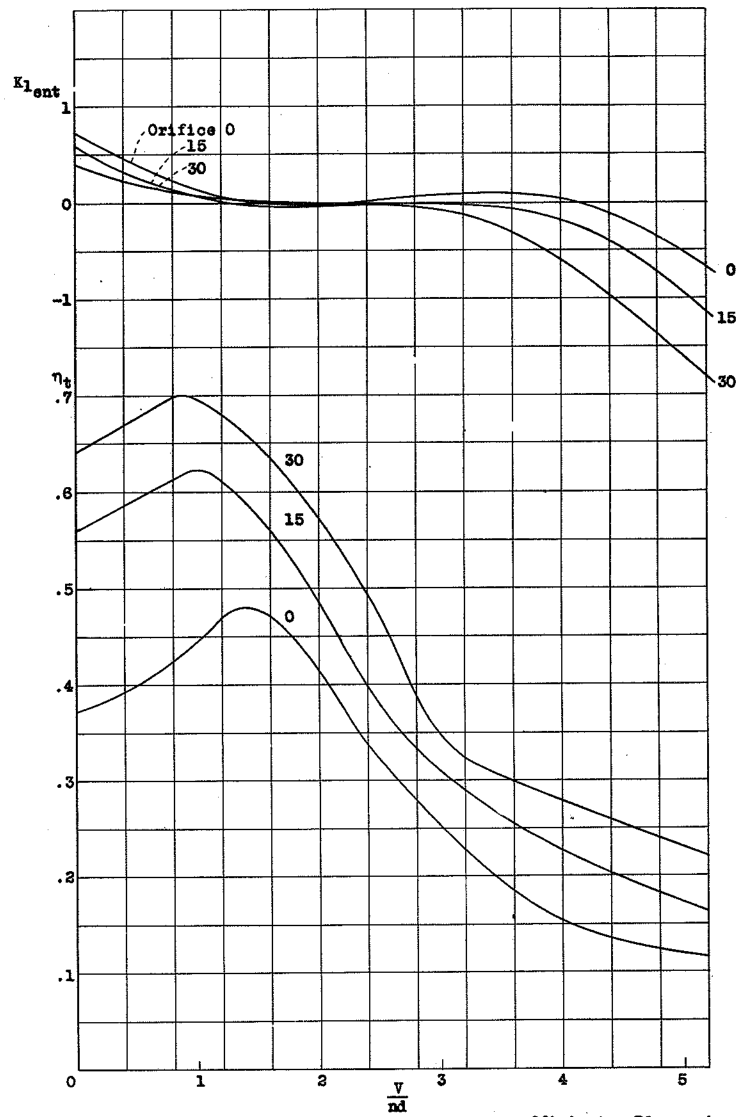

Figure 27.- Efficiency and entrance pressure coefficients. Blower 4. Side entrances in front position. Entrance lips built up.

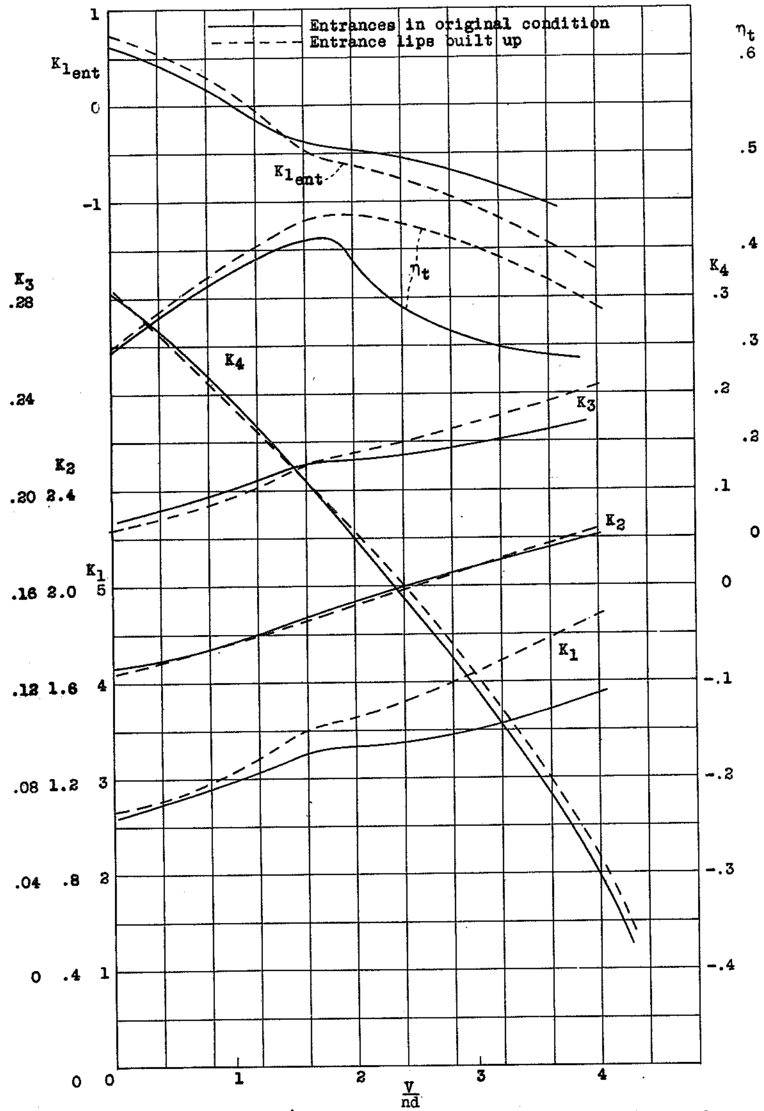

Figure 28.- Effect of building up side entrance lips. Blower 2. Entrance angle, 25°. Orifice 15.

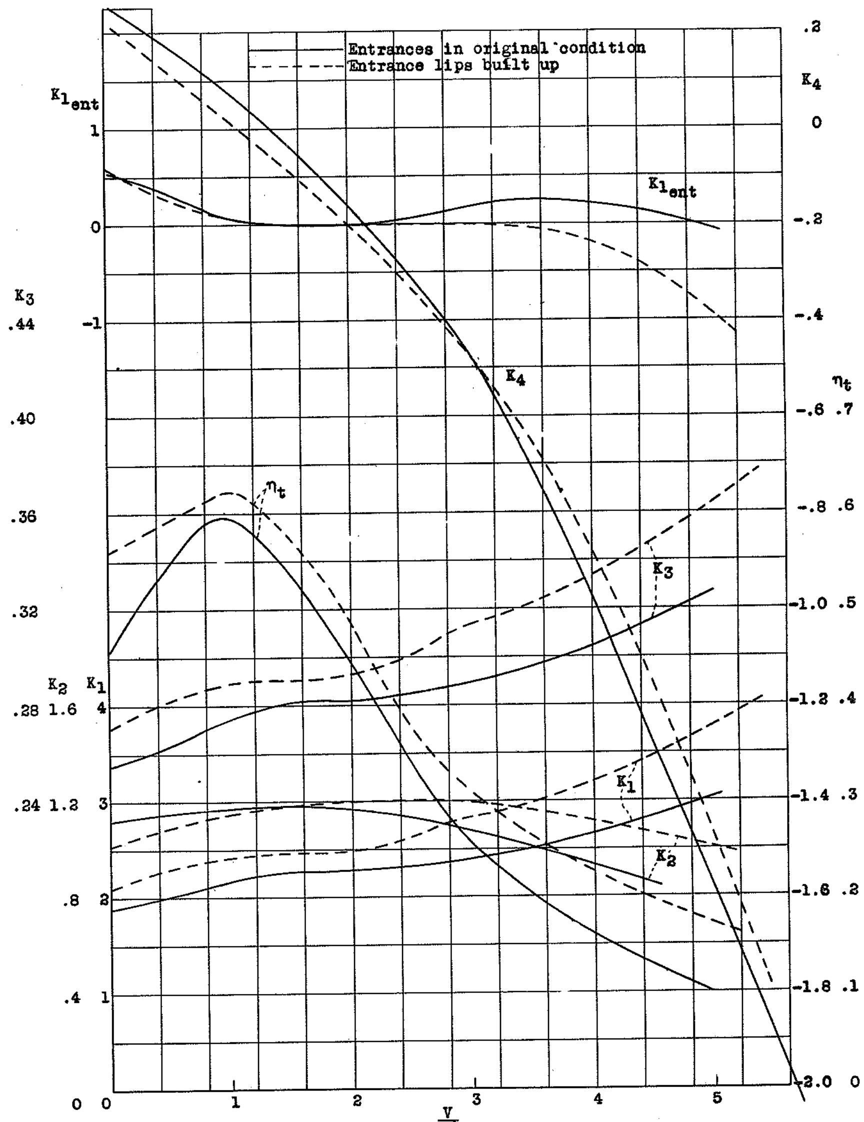

Figure 29.- Effect of building up side entrance lips. Blower 4. Entrance angle, 25°. Orifice 15.

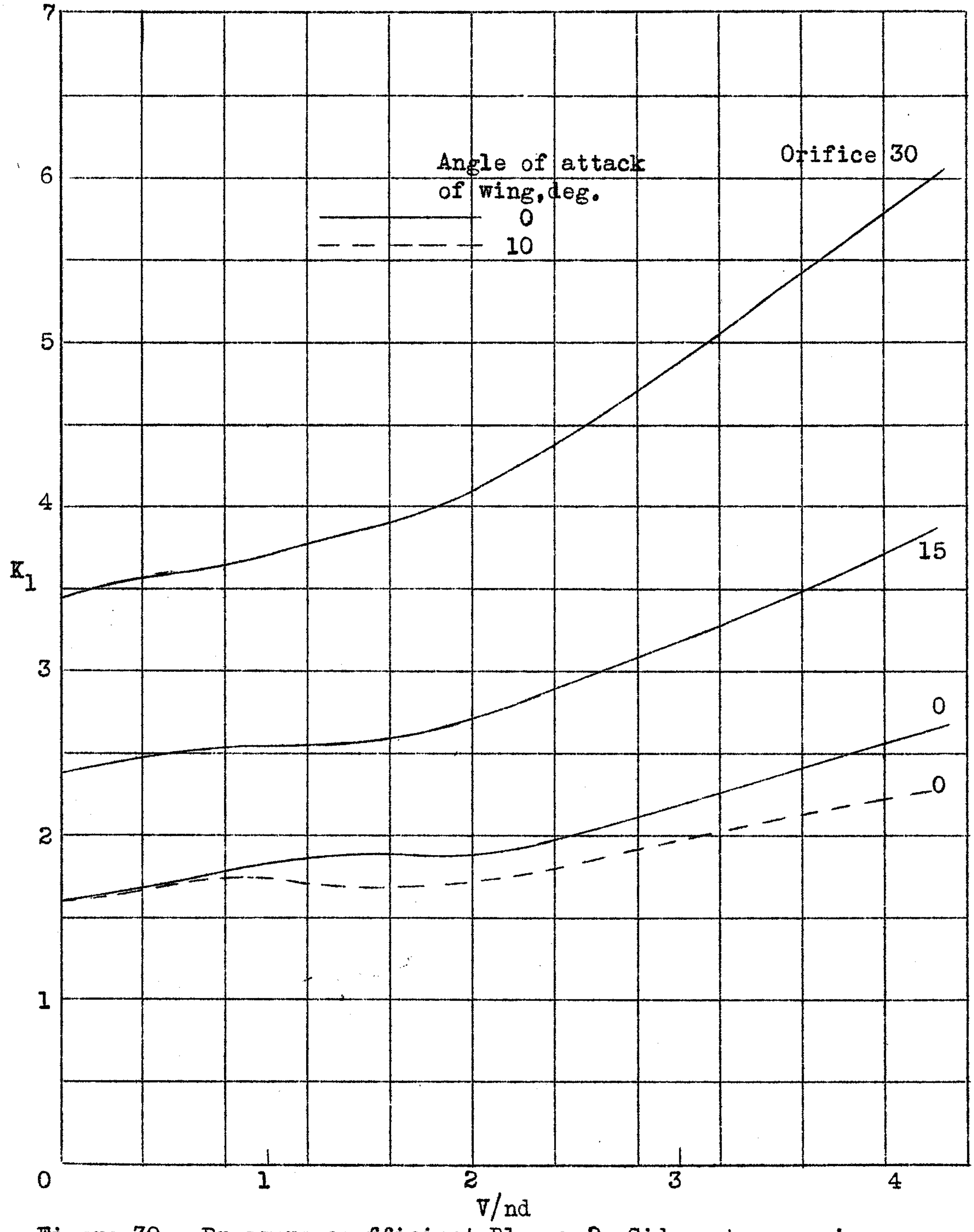

Figure 30.- Pressure coefficient. Blower 2. Side entrances in rear position with lips built up.

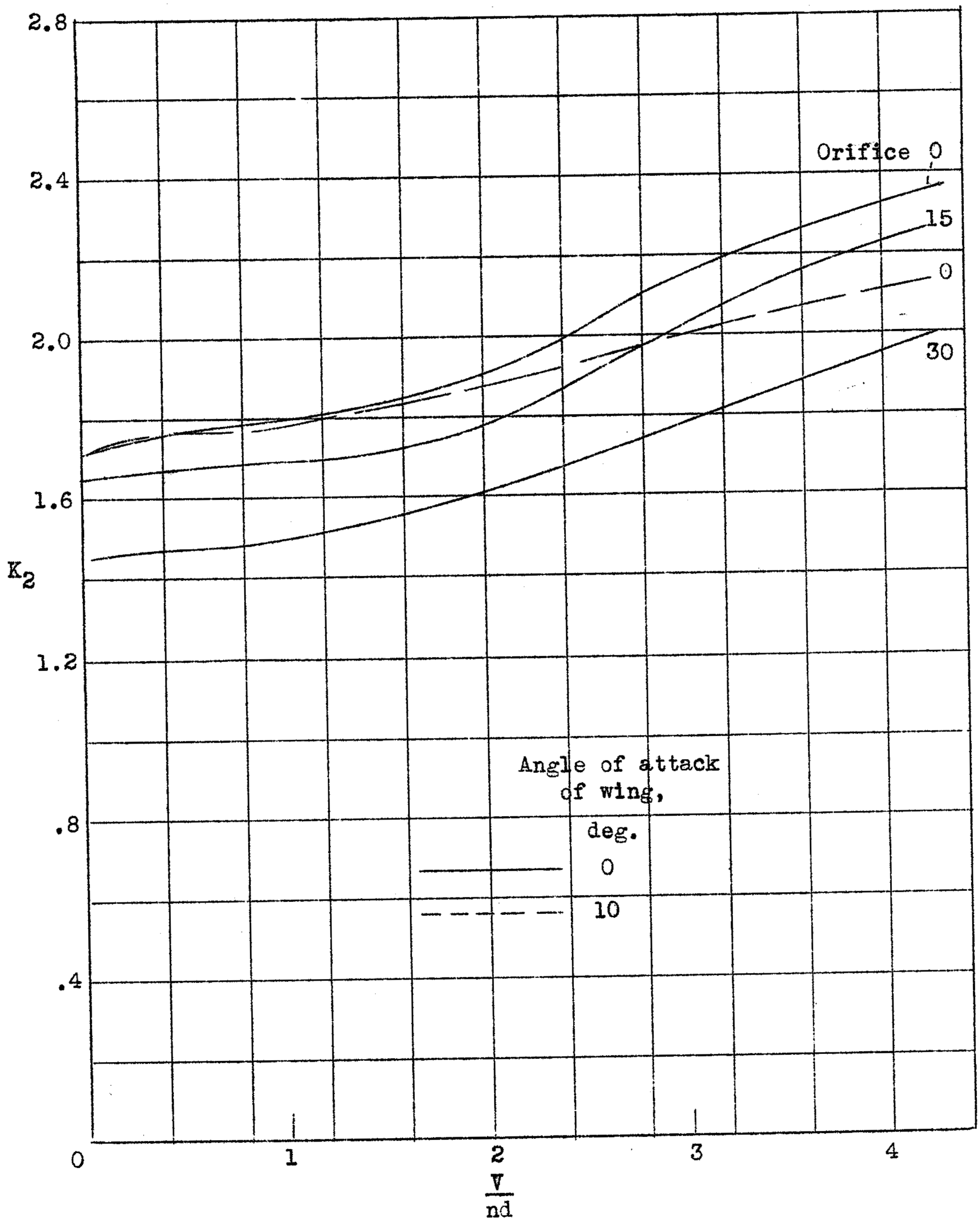

Figure 31.- Power coefficient. Blower 2. Side entrances in rear position with lips built up.

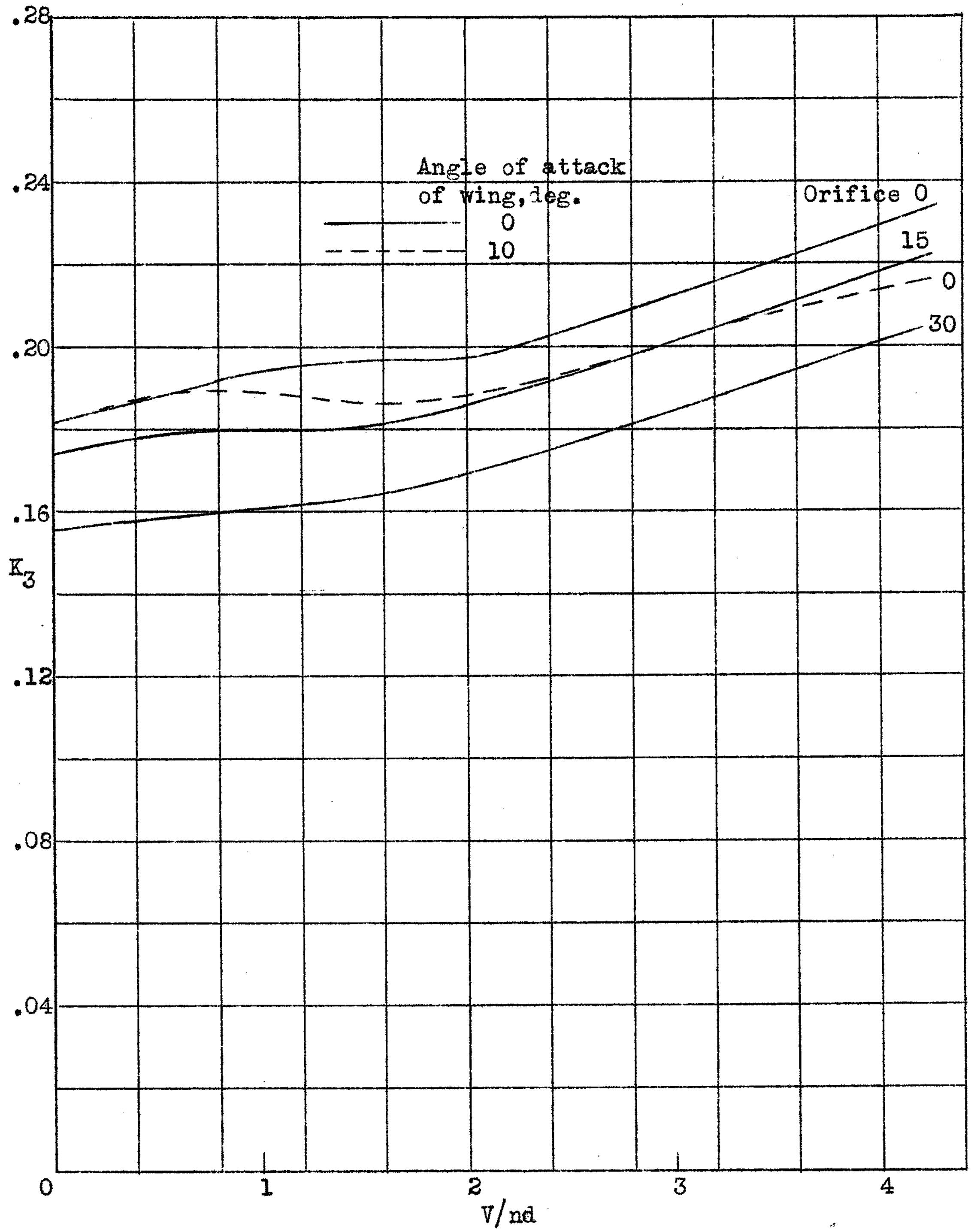

Figure 32.- Volume coefficient. Blower 2. Side entrances in rear position with lips built up.

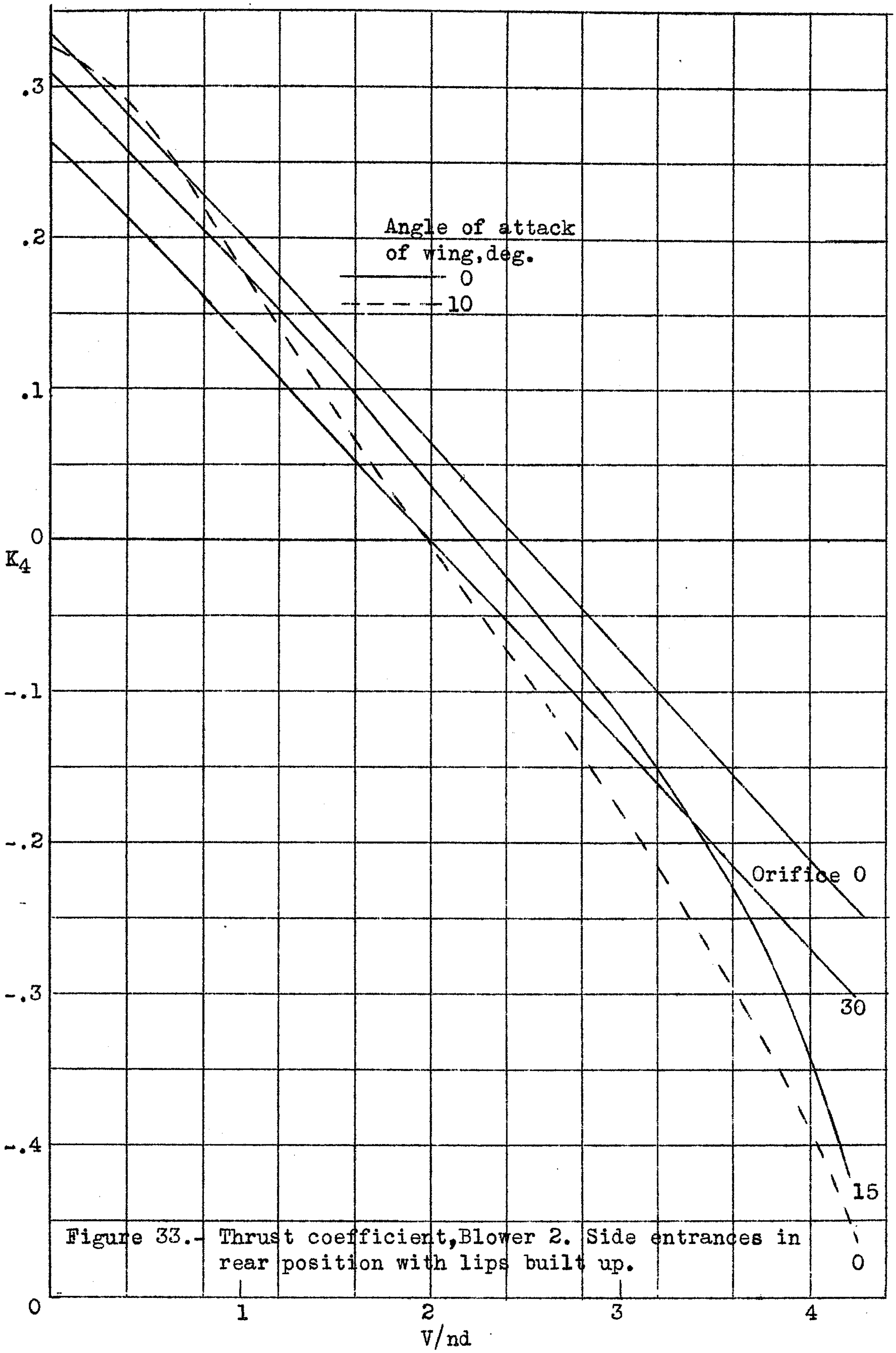

Figure 33.- Thrust coefficient, Blower 2. Side entrances in rear position with lips built up.

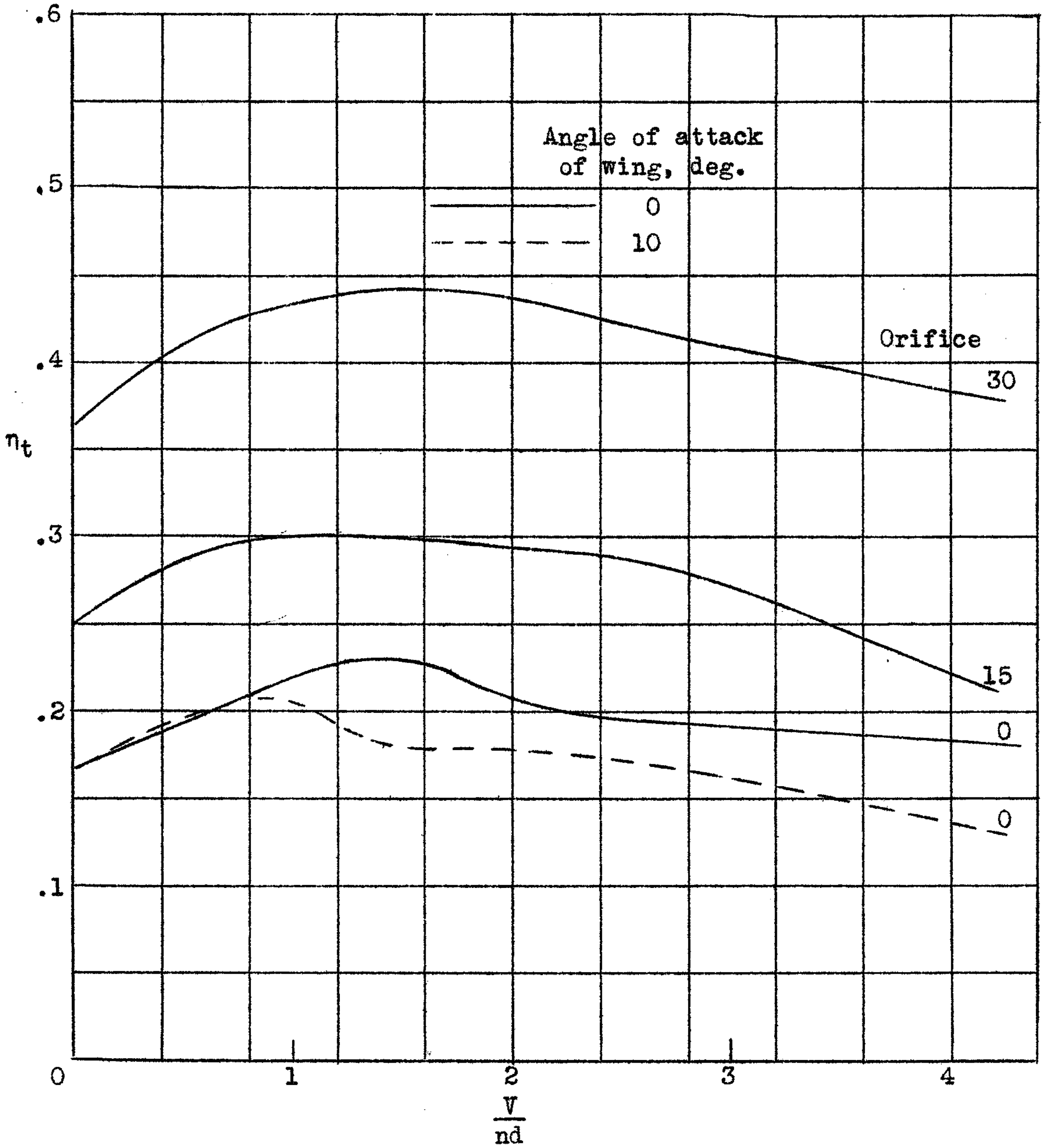

Figure 34.- Efficiency. Blower 2. Side entrances in rear position with lips built up.

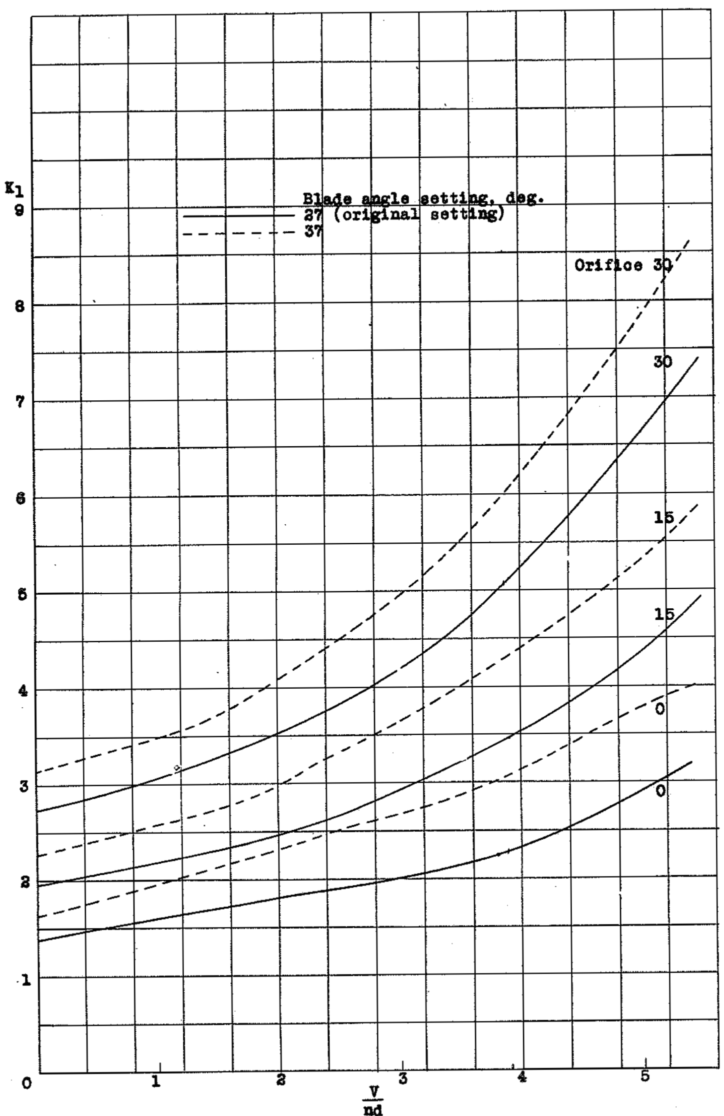

Figure 35.- Pressure coefficient. Blower 4. Side entrances in rear position with lips built up.

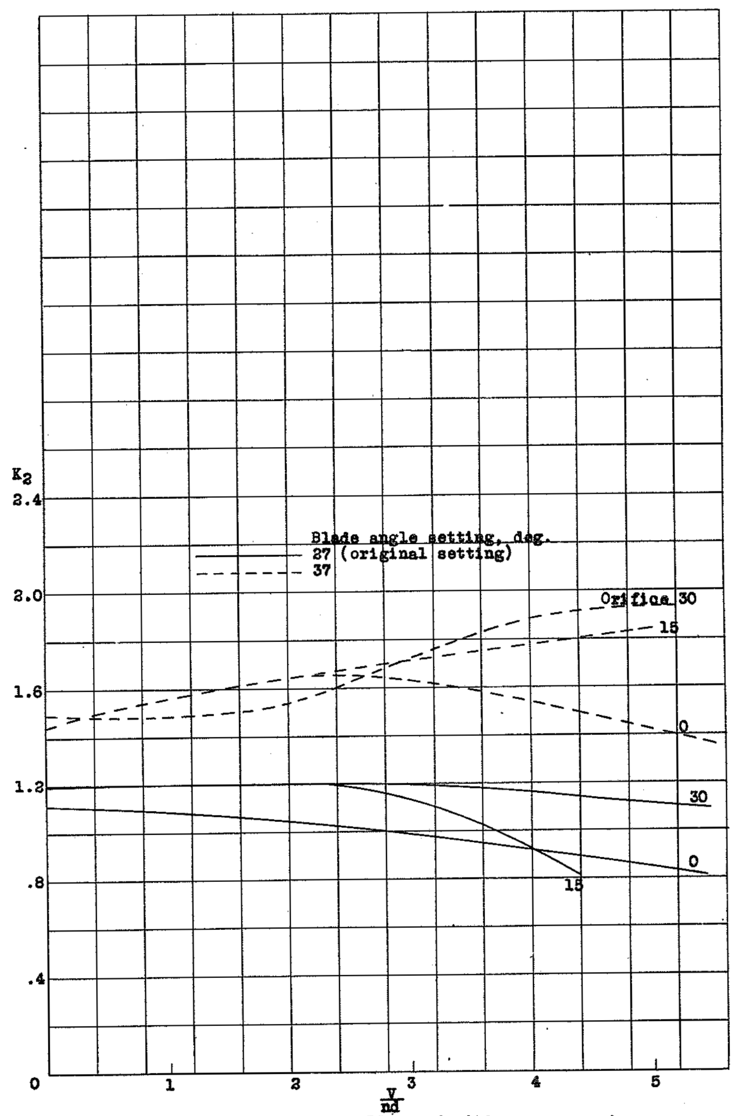

Figure 36.- Power coefficient. Blower 4. Side entrances in rear position with lips built up.

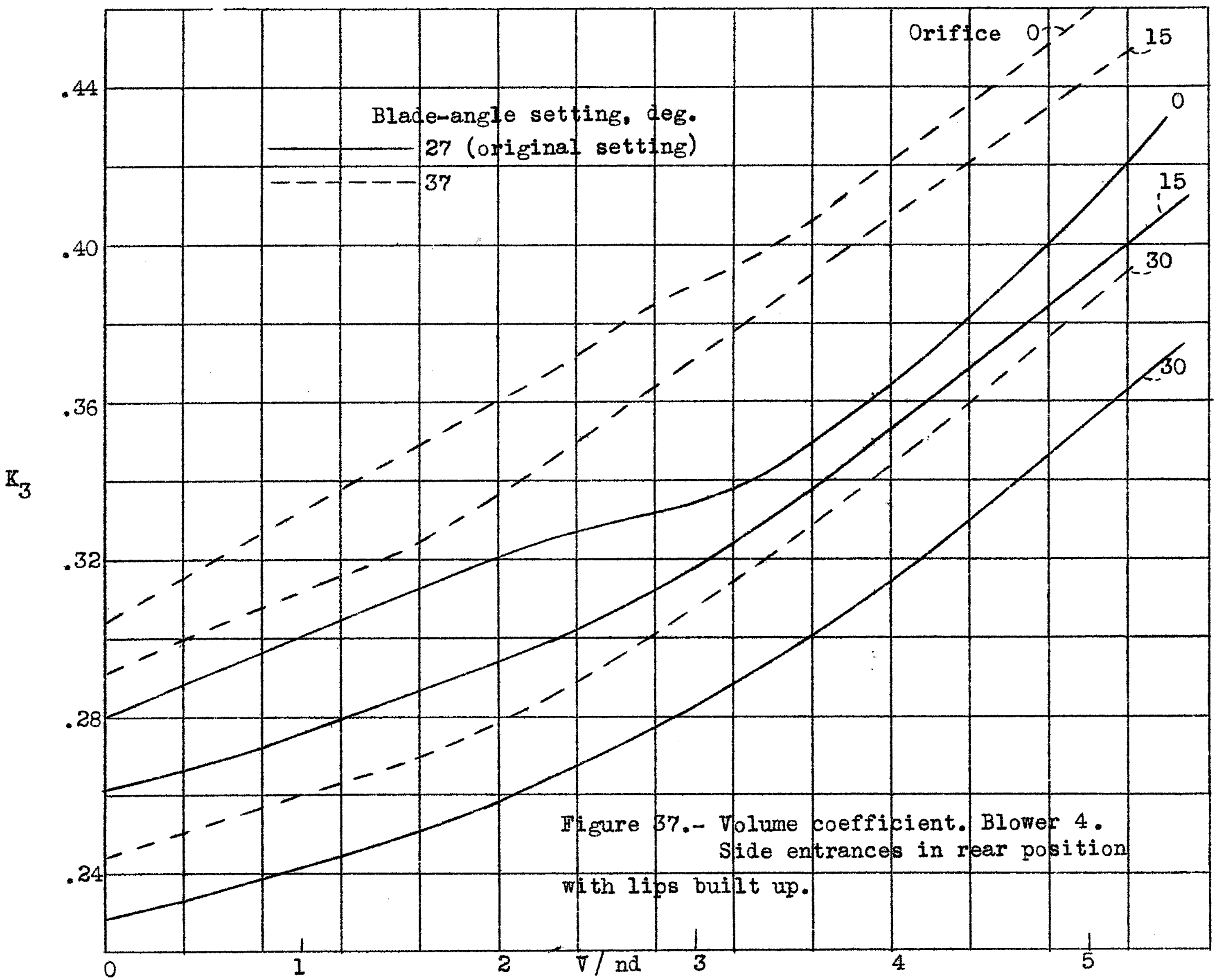

Figure 37.- Volume coefficient. Blower 4. Side entrances in rear position with lips built up.

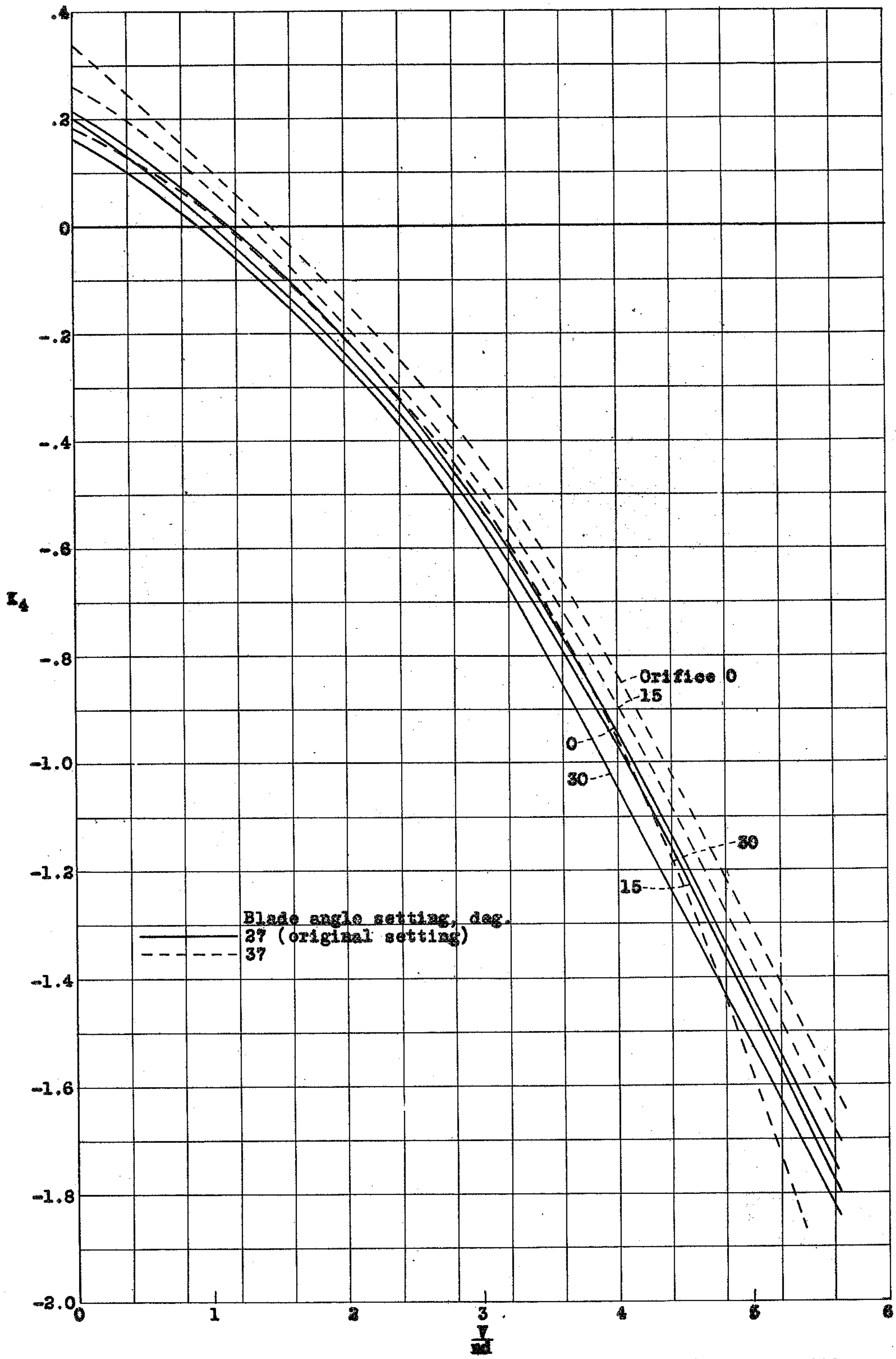

Figure 38.- Thrust coefficient. Blower 4. Side entrances in rear position with lips built up.

N.A.C.A. Fig. 39

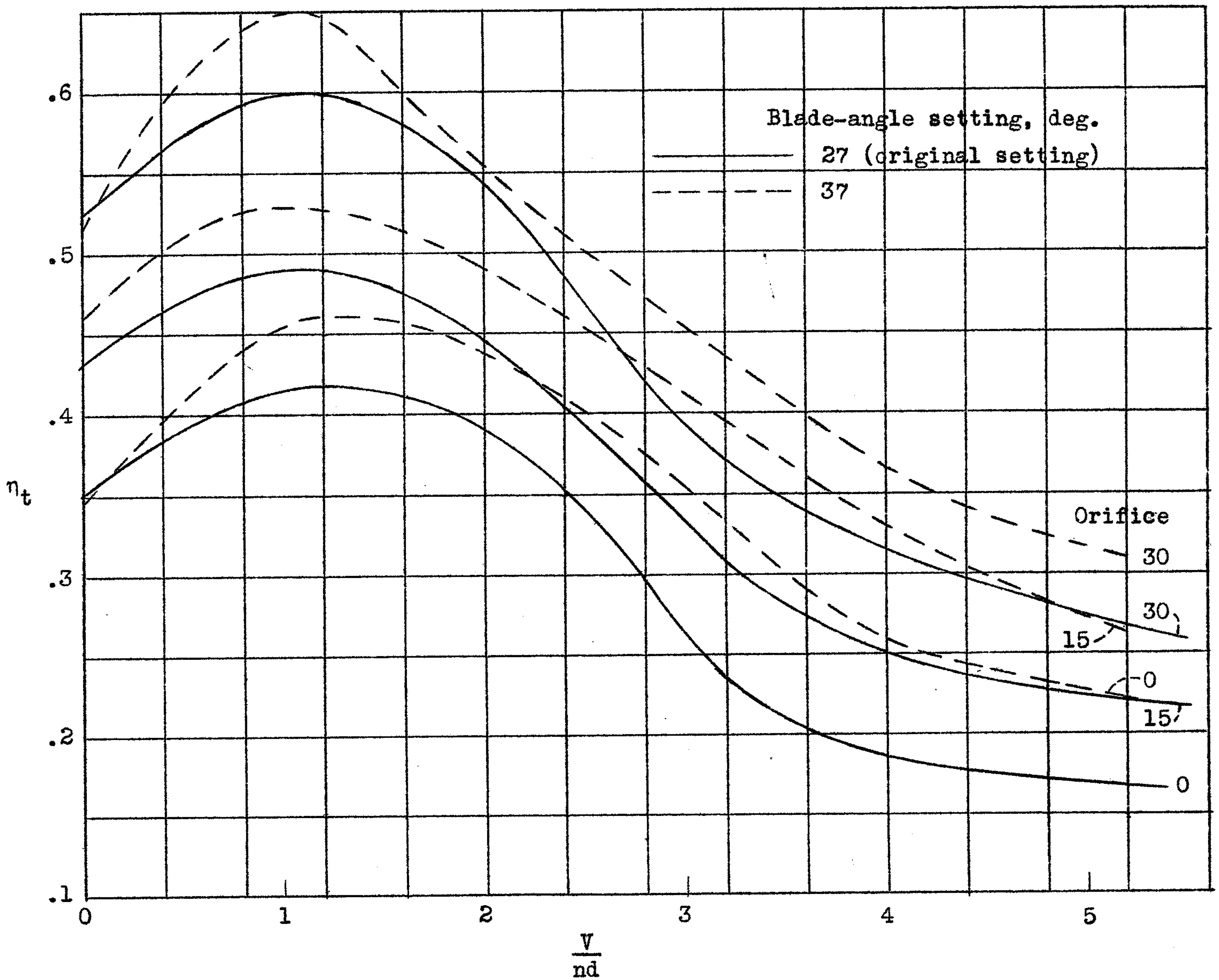

Figure 39.- Efficiency. Blower 4. Side entrances in rear position with lips built up.

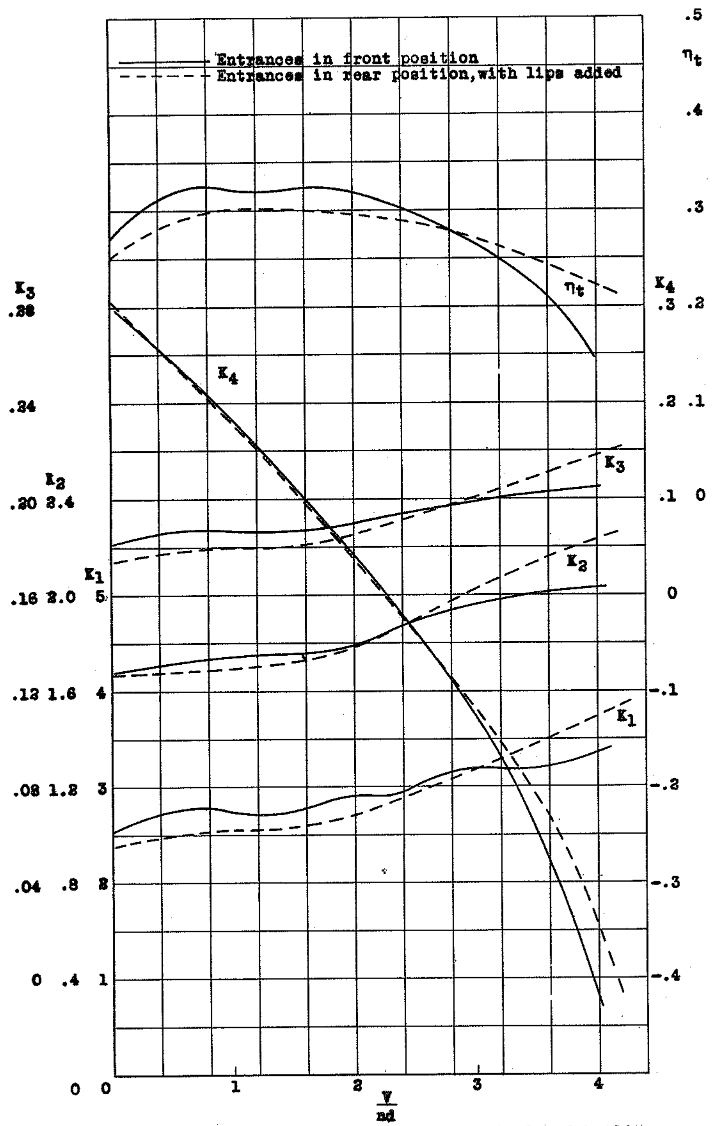

Figure 40.- Effect of moving side entrances back and building up lips. Blower 2. Entrances set 15°. Orifice 15.

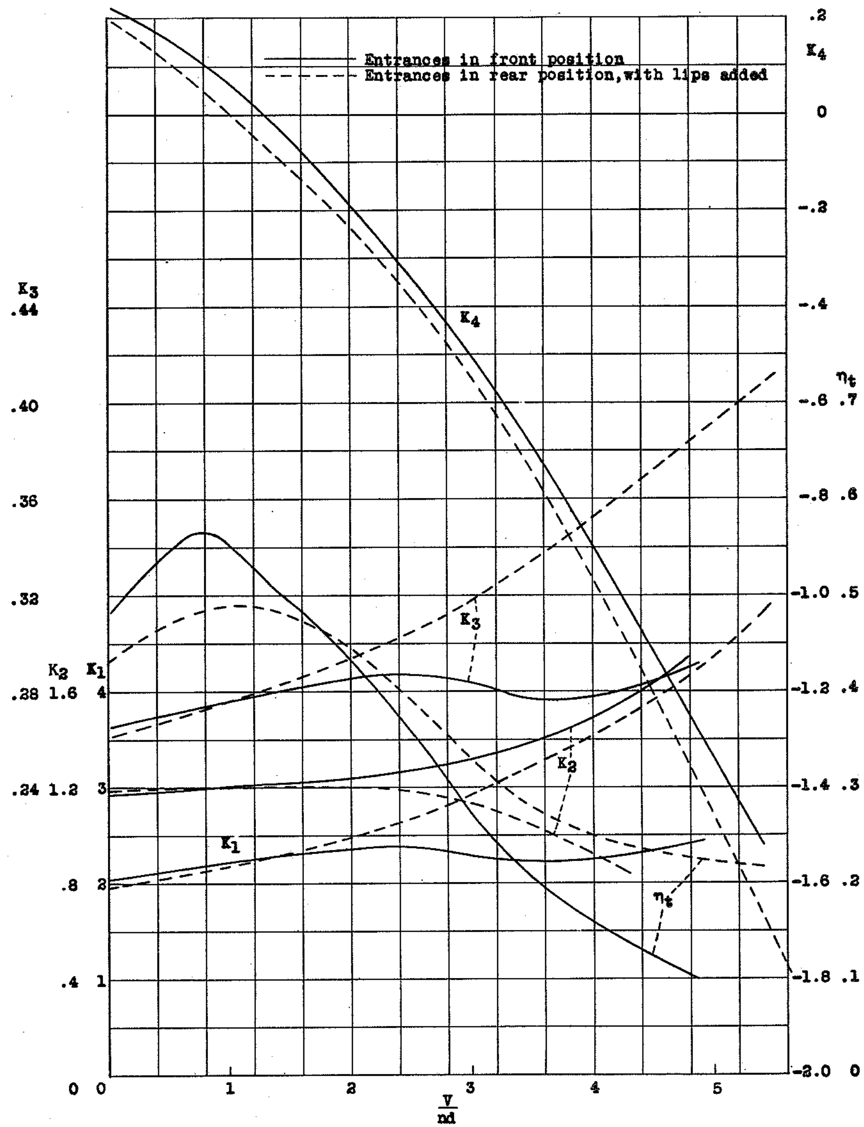

Figure 41.- Effect of moving side entrances back and building up lips. Blower 4. Entrances set 15°. Orifice 15.

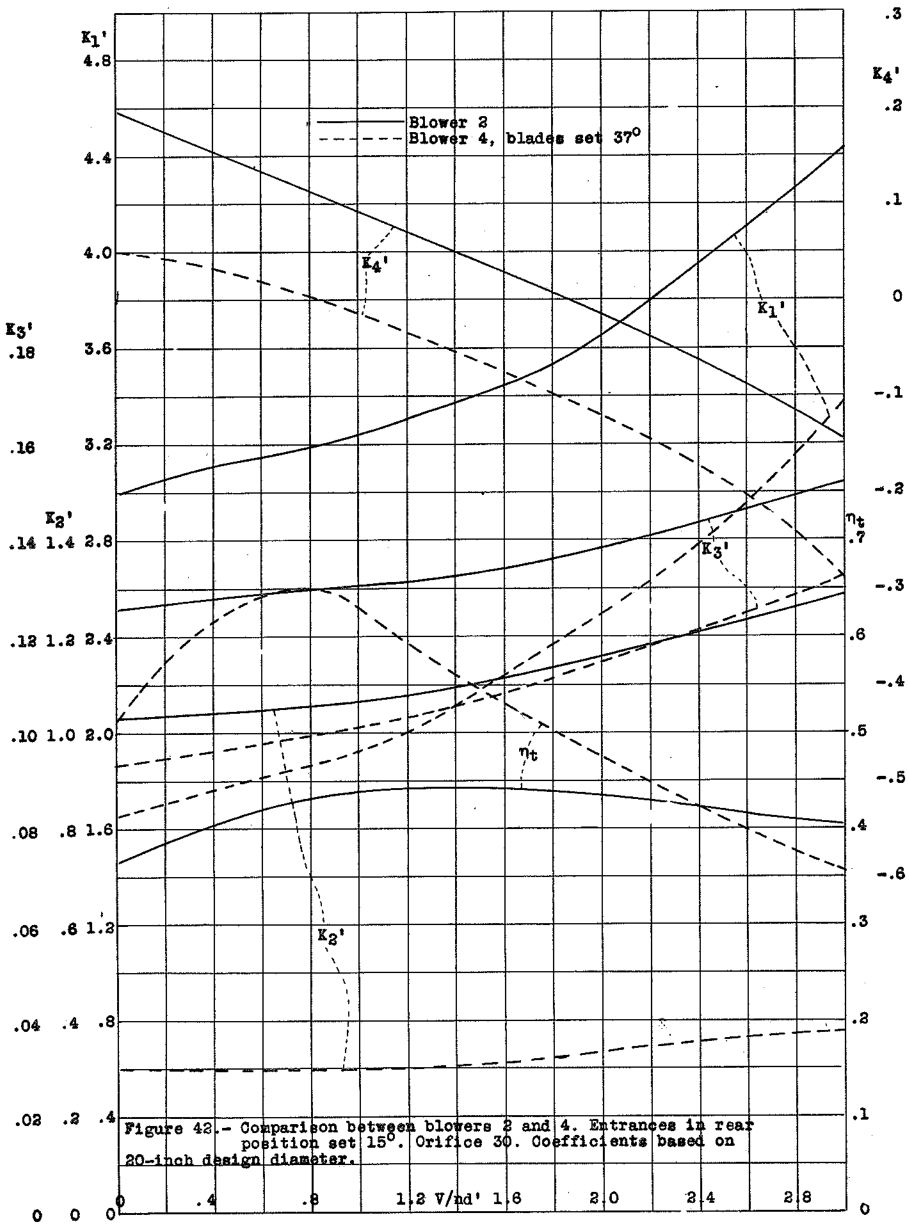

Figure 42.- Comparison between blowers 2 and 4. Entrances in rear position set 15°. Orifice 30. Coefficients based on 20-inch design diameter.

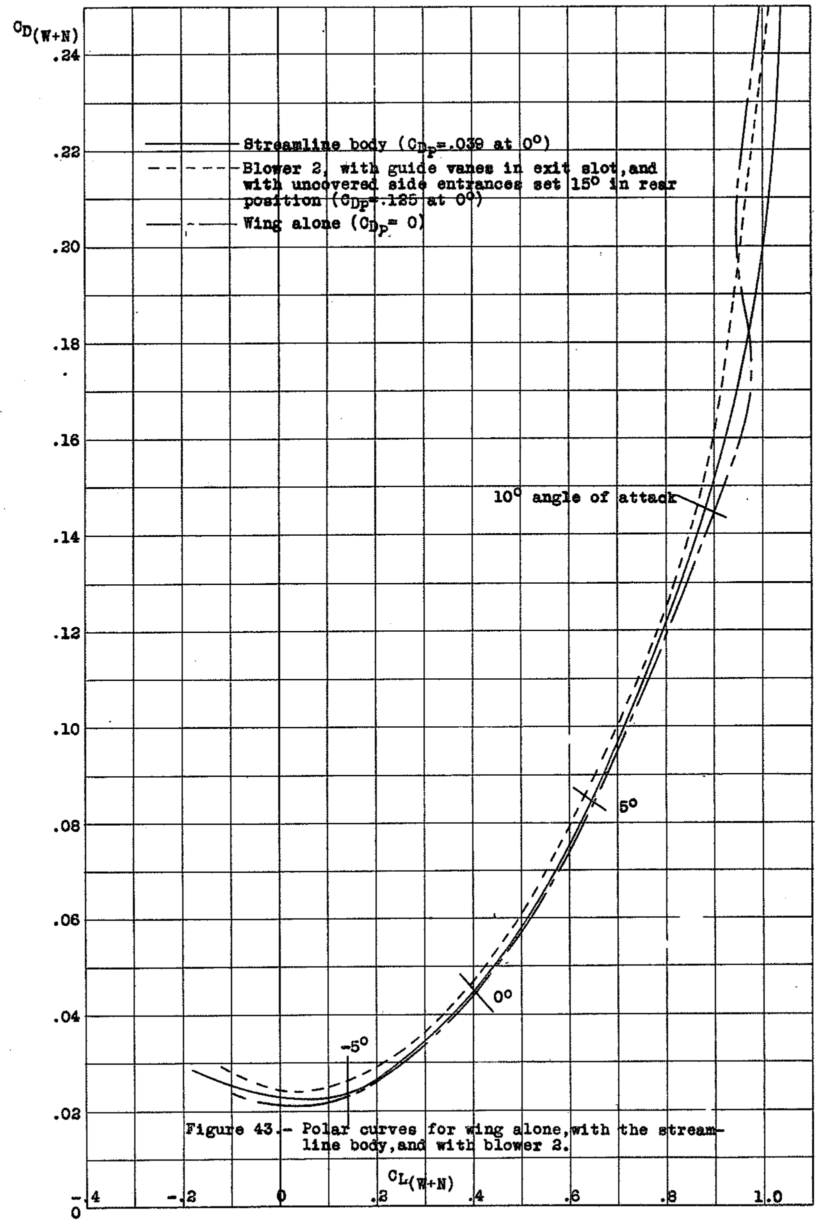

Figure 43.- Polar curves for wing alone, with the streamline body, and with blower 2.

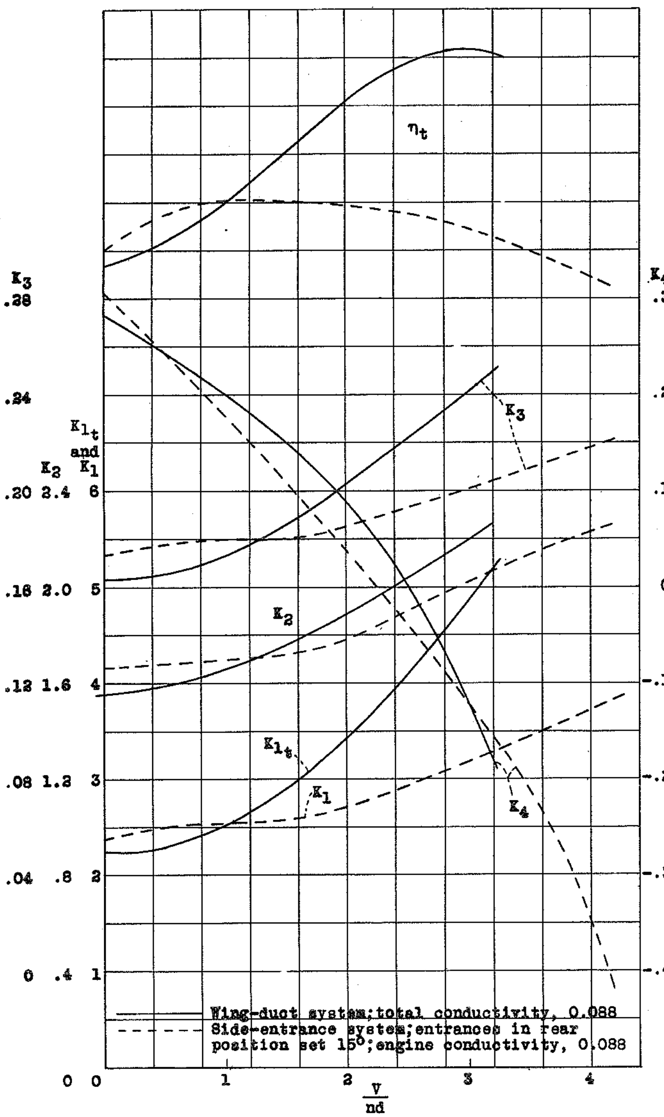

Figure 44.- Comparison between wing-duct and side-entrance systems. Blower 2.

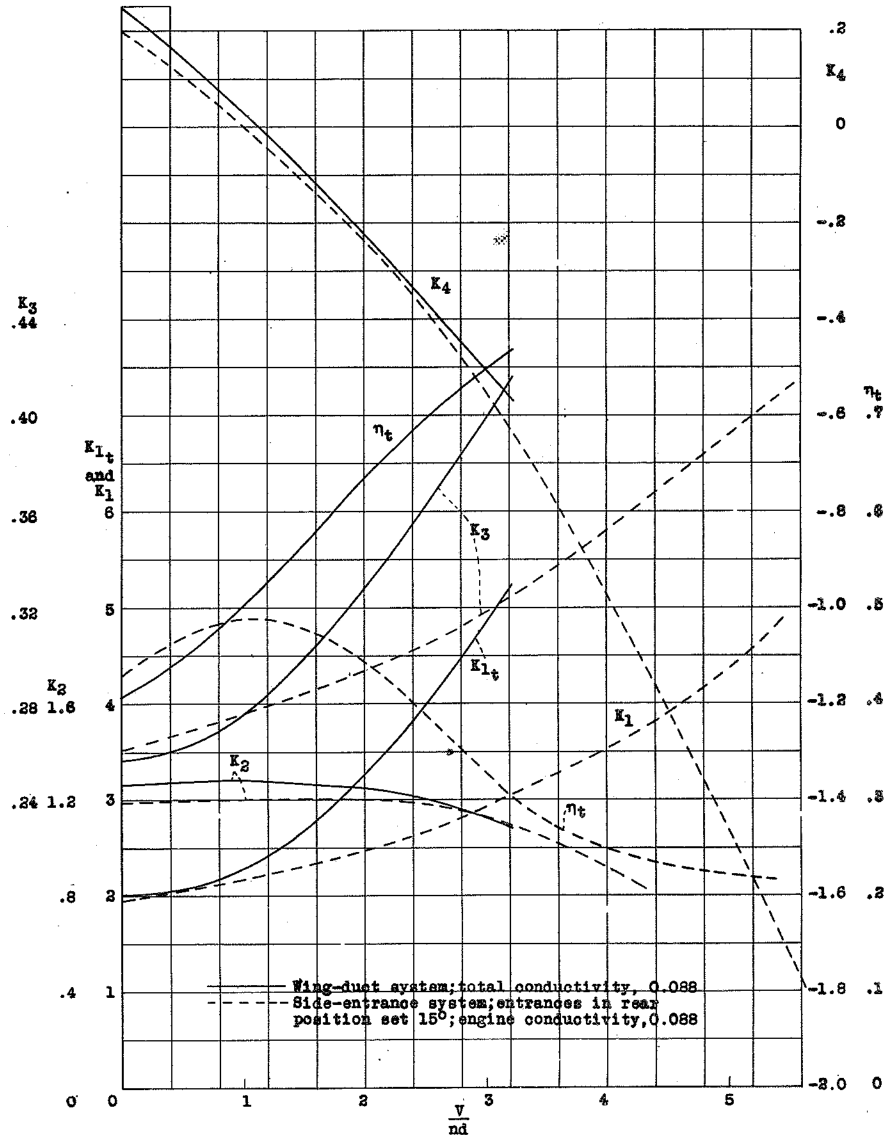

Figure 45.- Comparison between wing-duct and side-entrance systems. Blower 4.

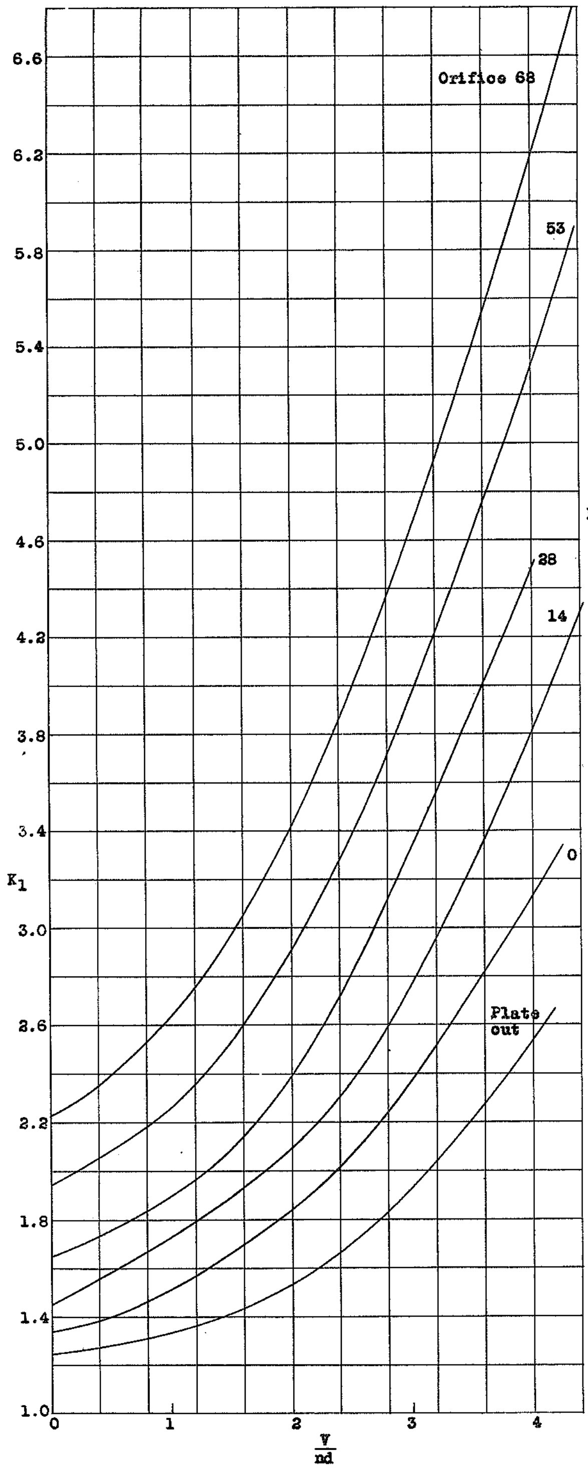

Figure 46.- Pressure coefficient. Blower 5.

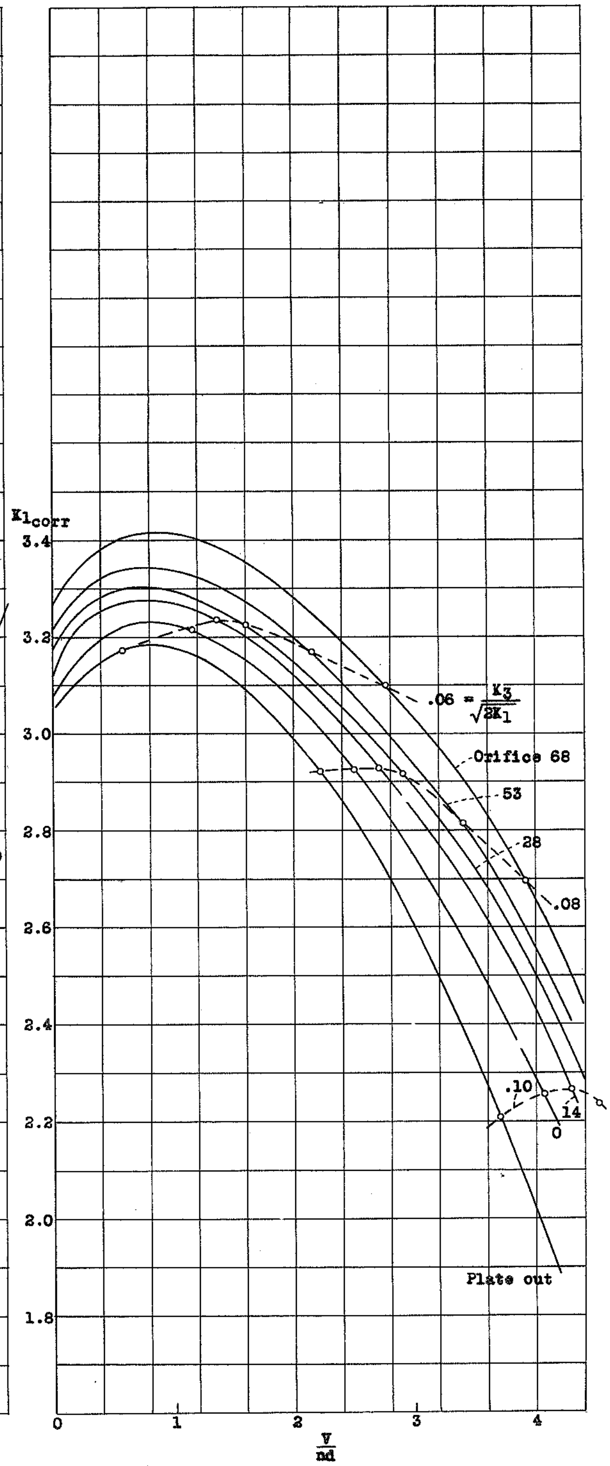

Figure 47.- Pressure coefficient corrected for tail-pipe restriction. Blower 5.

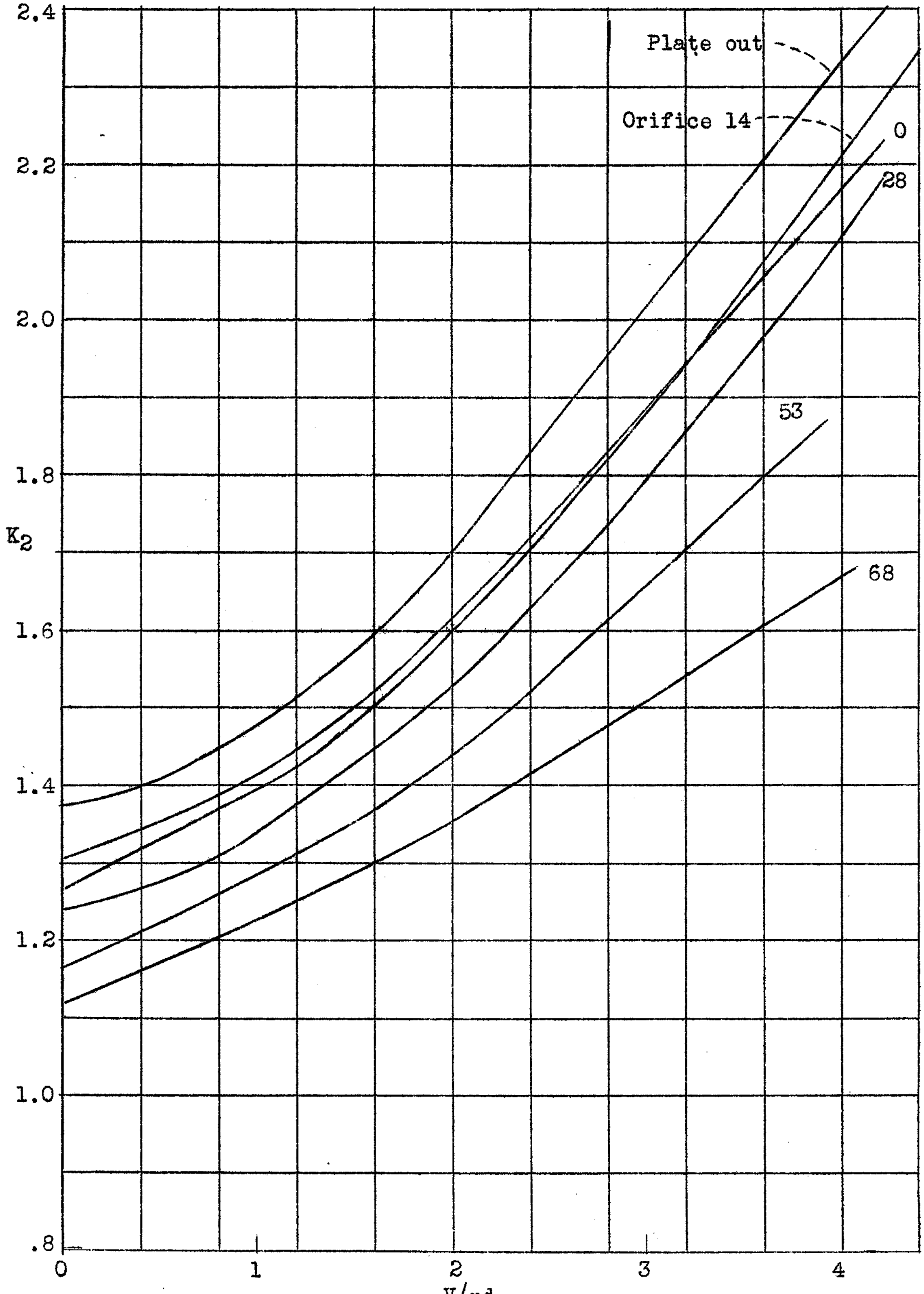

Figure 48.- Power coefficient. Blower 5.

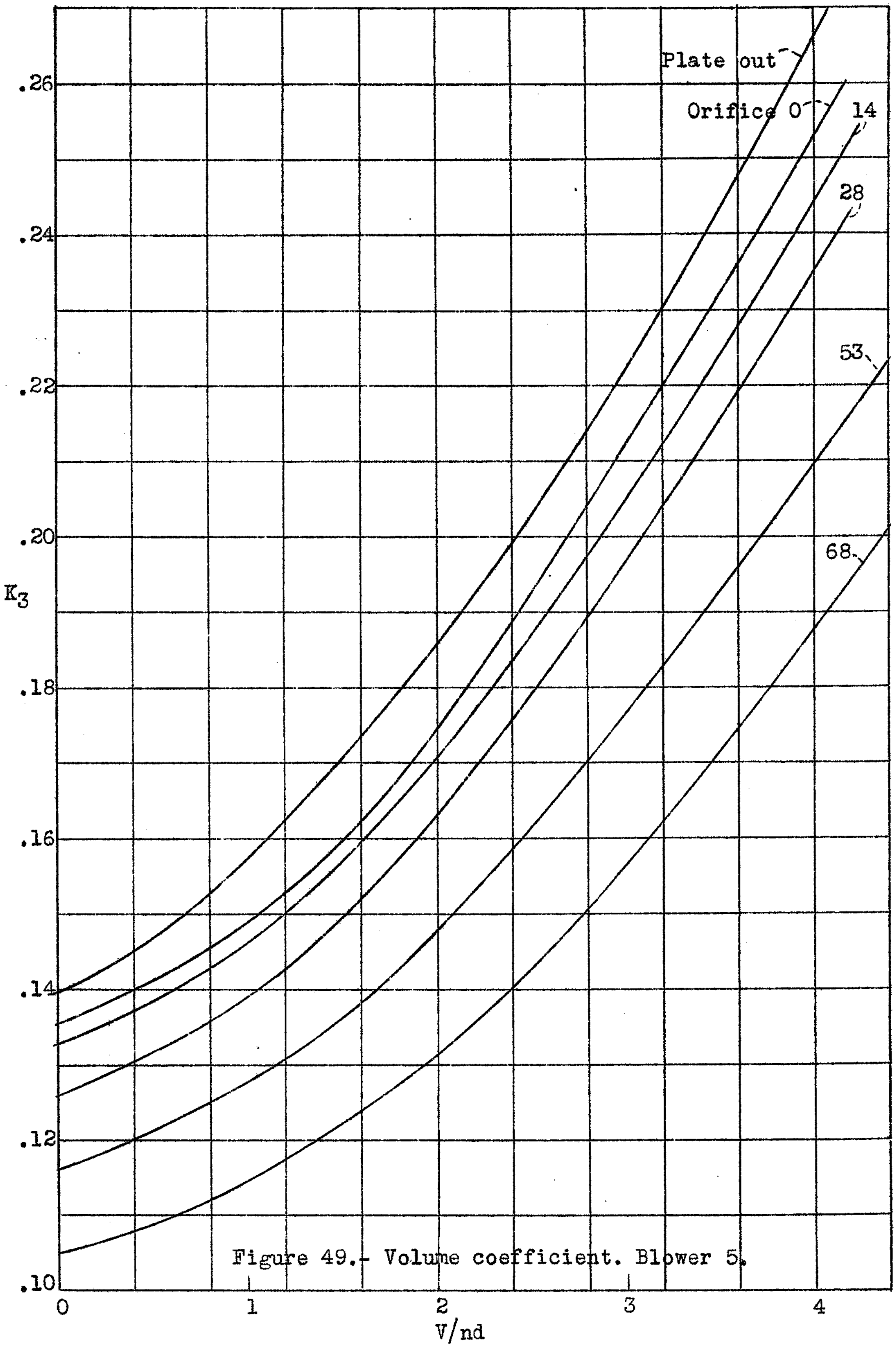

Figure 49.- Volume coefficient. Blower 5.

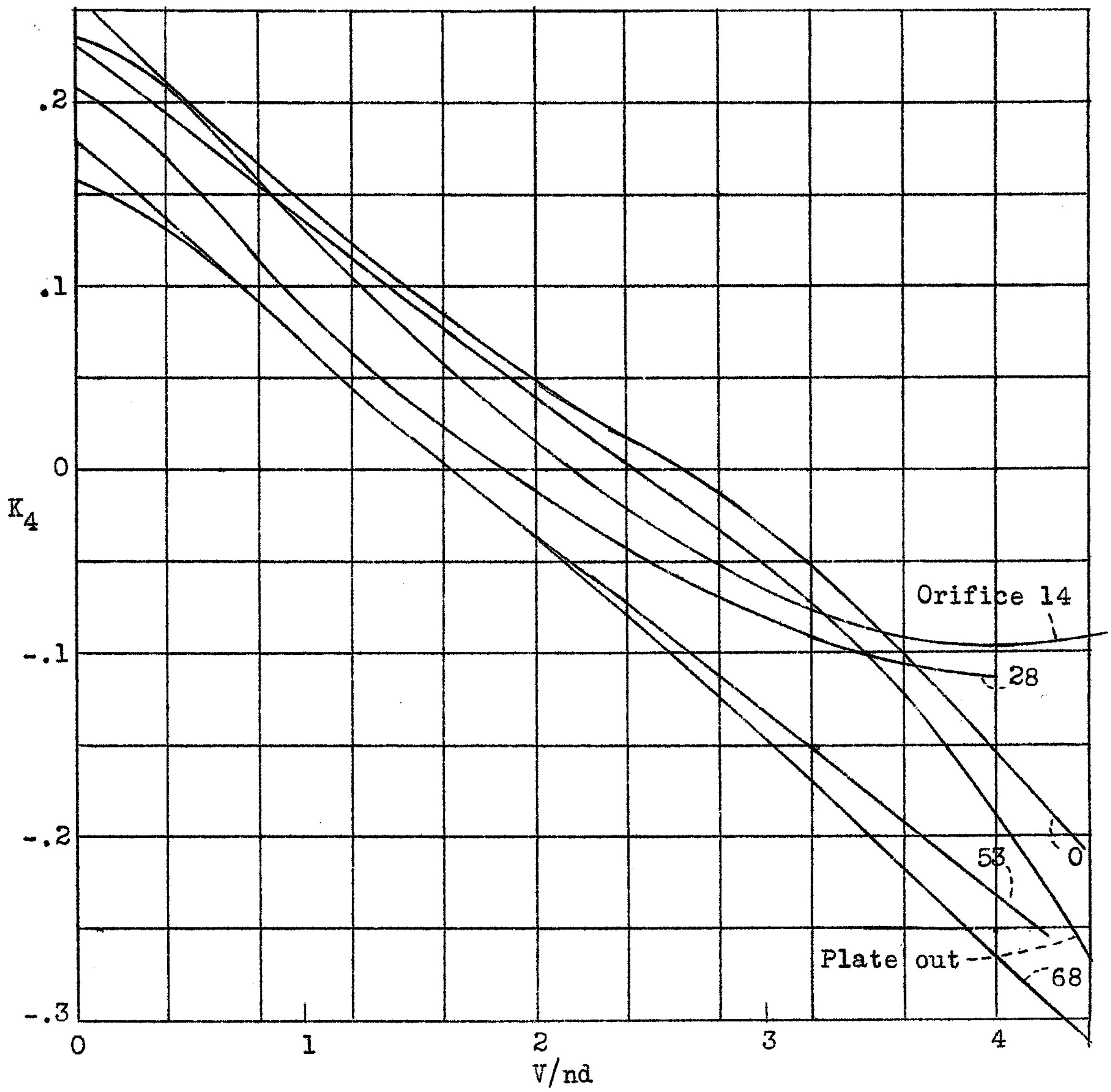

Figure 50.- Thrust coefficient. Blower 5.

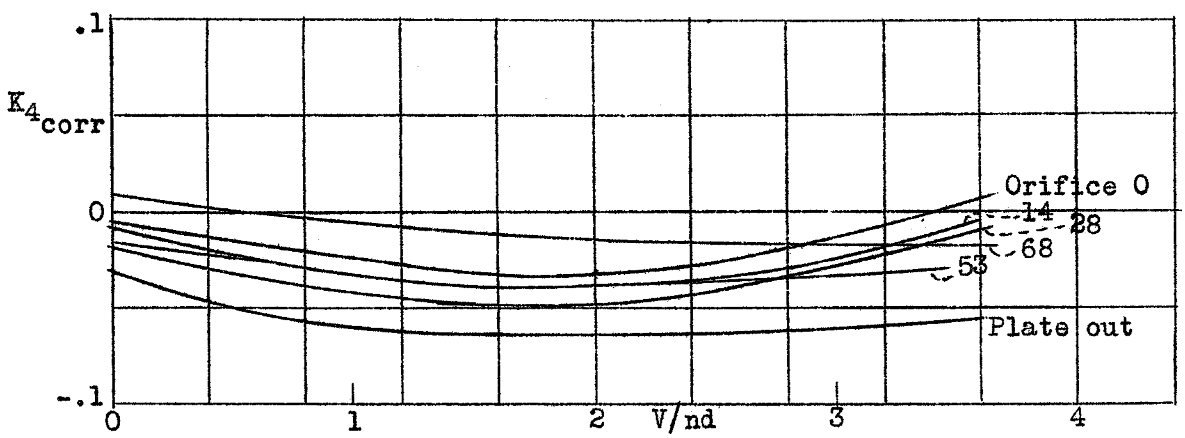

Figure 51.- Thrust coefficient corrected for tail-pipe restriction. Blower 5.

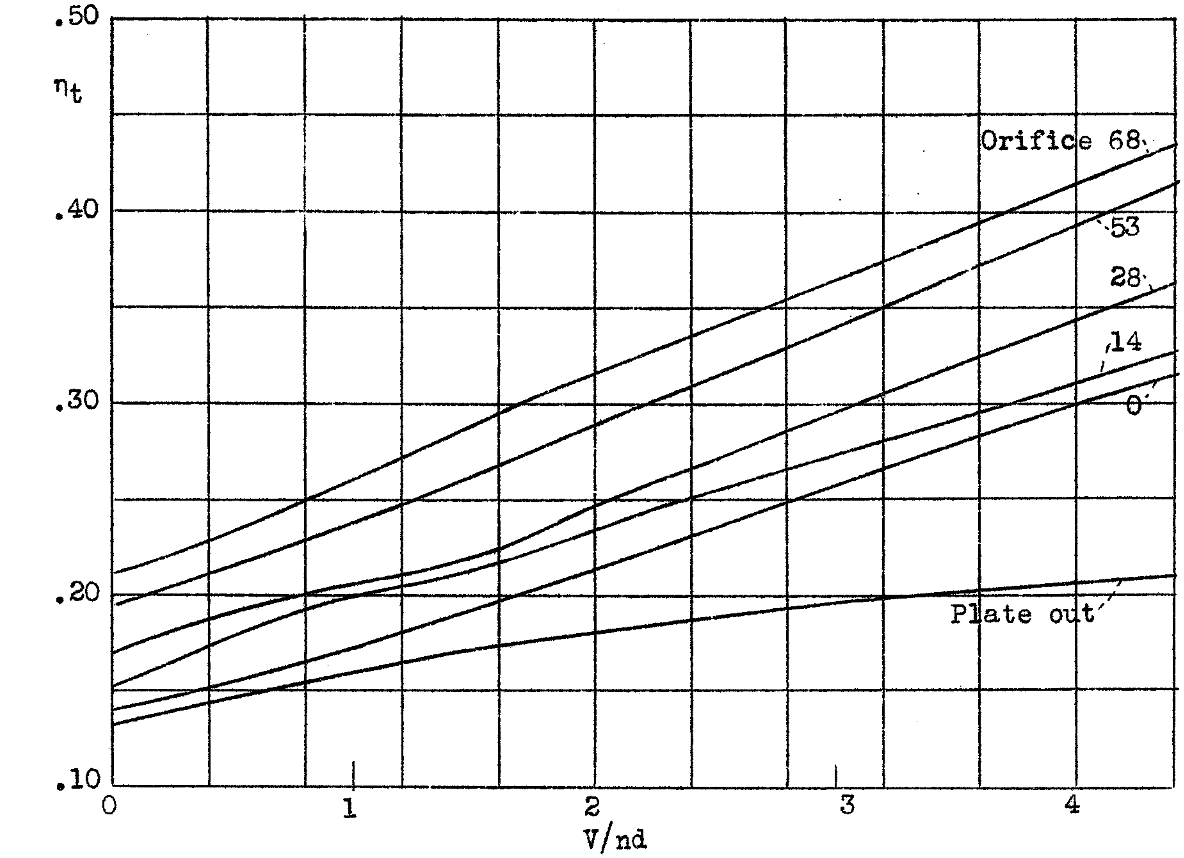

Figure 52.- Efficiency. Blower 5.

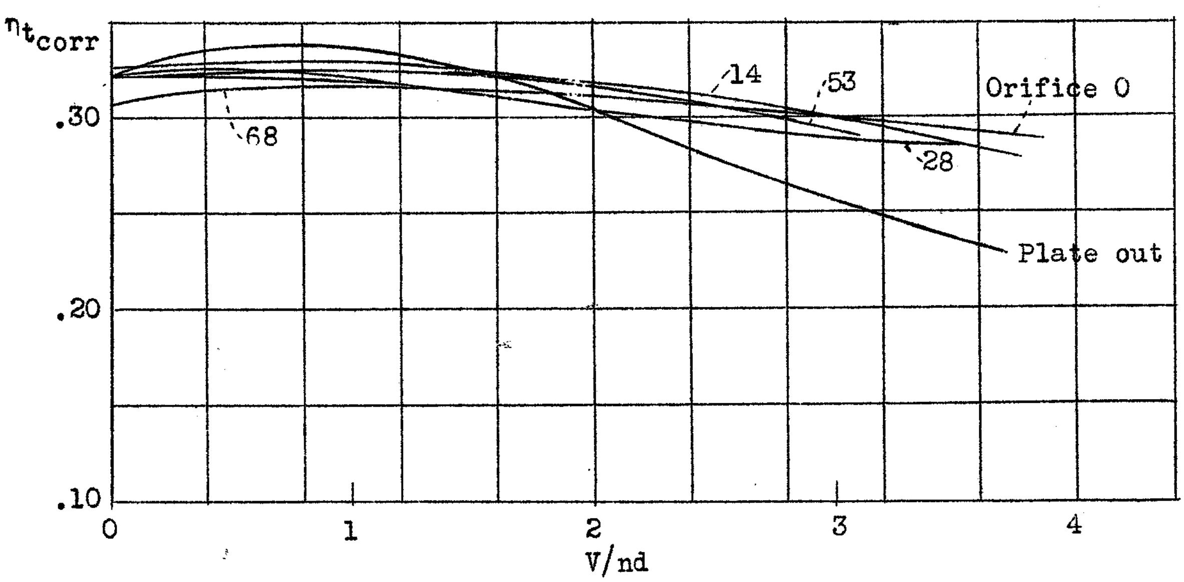

Figure 53.- Efficiency corrected for tail-pipe restriction. Blower 5.